PROCEEDINGS

BUILDING FOR SUSTAINABLE DEVELOPMENT

A Nuts and Bolts Approach

Conference C74 of the SOLAR ENERGY Society
Royal Institute of British Architects, London
26 May 2000

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"Building for Sustainable Development - A Nuts and Bolts Approach"

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c/o School of Engineering, Oxford Brookes University, Gipsy Lane Campus, Headington, Oxford OX3 0BP
Tel +44 (0)1865 484367
Fax +44 (0)1865 484263
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Technologies For Sustainable Buildings

Brian Norton* , Philip Eames* and Henry Skates+

*Centre for Sustainable Technologies, University of Ulster,
Newtownabbey, BT37 0QB, N Ireland
+Centre for Building Performance Research, Victoria University of Wellington,
Wellington, New Zealand.

Abstract
The strategic issues underlying the selection of appropriate technologies that contribute to the environmental sustainability of buildings are discussed. Specific examples of building technologies that facilitate the goal of achieving sustainability are described.

Keywords
Sustainable buildings; renewable energy; material use; environmental impact; life cycle analysis; building technologies.

Introduction
Buildings have individual and collective, direct and indirect, impacts on the environment both present and future as illustrated in Fig. 1. Each building, by occupying land, alters the ground and vegetation, changes water courses and wildlife habitats and, in both construction and use, consumes resources, labour, materials and fuel for power, heating and maintenance. Within the European Union it has been estimated that buildings consume about 40% of energy, produce 30% of carbon dioxide emissions and generate 40% of waste materials. Sustainability, in this instance, means "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainable construction is thus the "creation and responsible tenure of a healthy built environment based on resource efficient and ecological principles" (Kilbert, 1994). This is accomplished through the adoption of a holistic view of the world and human interactions with it, under which every function is cognisant of and within the limits of both the local and global ecosystems. This perspective has been summed-up by the phrase "think global, act local".

Broad strategies to achieving sustainable buildings are summarised in Table 1

Table 1. Strategies leading to Sustainable Buildings

Objective	Strategy
Use less: energy, materials, water, land	reuse, recycling, use of renewables, efficient use, life-cycle design, renovation;
Conserve: natural environment, bio-diversity	restrict land use, prevent pollution, ecological harmony;
Maintain: healthy indoor environment accessible outdoor environment	low emission materials, adequate ventilation, provision of public transport, amenities, services, noise abatement, socially inclusive access;

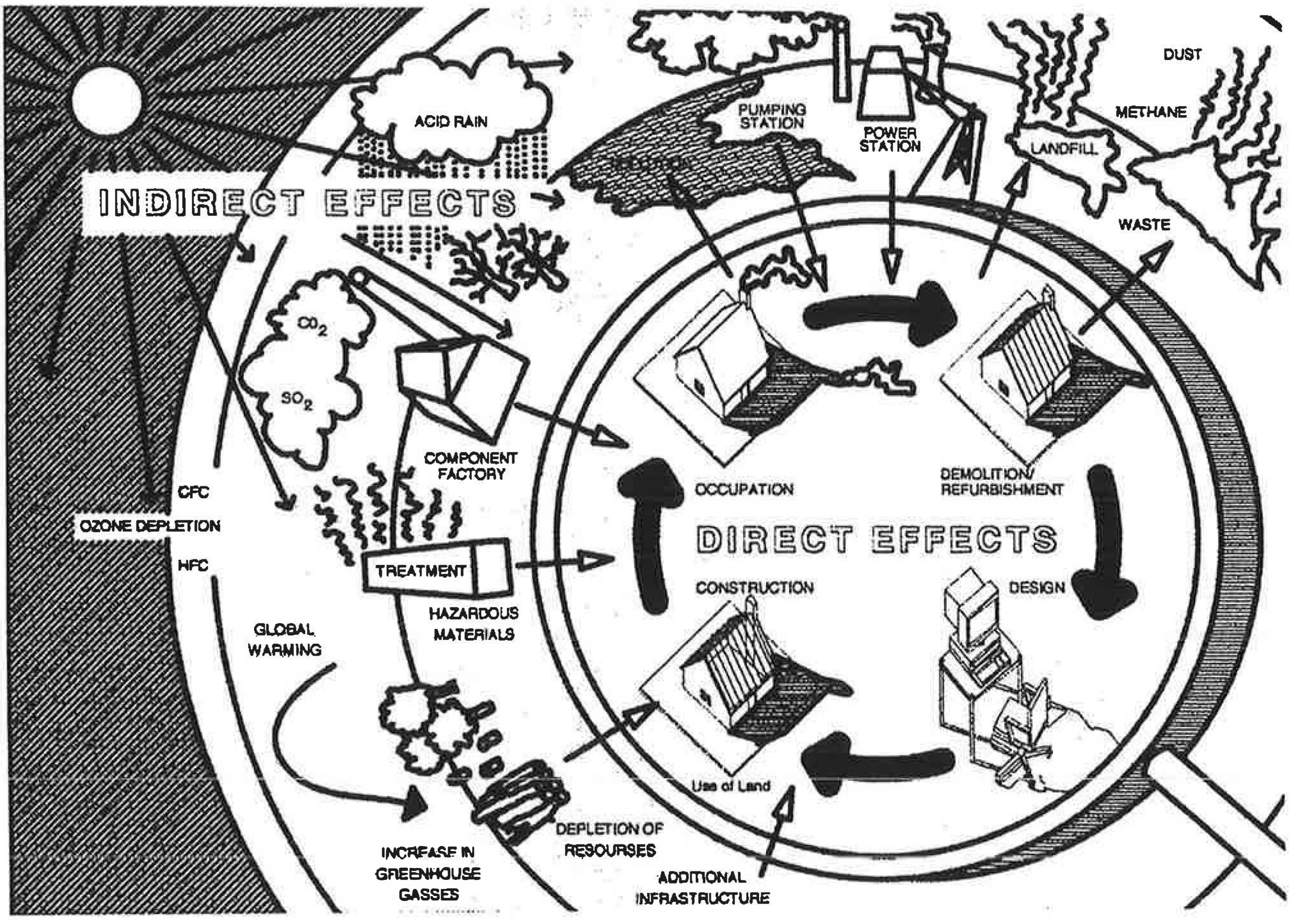

Figure 1 : Global-local links and impacts of buildings

Sustainable buildings are thus characterised over their period of use by:

- consuming minimal energy and water
- efficiently using environmentally-benign materials and energy
- minimising both direct and indirect waste and pollution including good indoor and outdoor air quality
- integrating harmoniously with the natural environment
- contributing by location and services to a sustainable urban form and transport system
- being safety constructed and healthy to use for all including those with special needs
- facilitating social development

These characteristics relate to diverse aspects, differently measured, of a building's commissioning, design, construction, occupation and demolition. An optimised strategy thus has to be underpinned by subjective value judgements as to the importance of each objective.

Sustainable buildings should use technologies, materials and energy to meet the following criteria:

- low energy use in the occupation of the building
- low embodied energy materials and products should be used where possible
- selection should be based on the source and origin being managed sustainably and where extraction, processing and manufacture conforms with environmental

management accreditation
- the needs of the users of the building are anticipated
- wherever possible recycled or reused materials should be used in construction, refurbishment and repair and all waste materials on site should be separately sorted and recycled or incorporated in the building
- the building should be designed to optimise opportunities on its proposed site, taking into consideration aesthetic and climatic factors as well as energy and material resources
- materials, which do not incorporate toxic solvents, chemicals, preservatives and synthetic resins, should be used to safeguard the health of construction workers and building occupants
- renewable technologies should be utilised where appropriate for electricity generation, heating and cooling
- the construction of a building should use local materials, requiring as little transportation of resources as possible

Governmental actions, and as a prerequisite, public demand, to promote economic and social sustainability are explicit. There are also crucial obligations on designers and constructors. This paper, however, focuses on building technologies that can facilitate the sustainability of buildings.

Technology Selection

The selection by designers of building component technologies can be conservative, which hinders the introduction of new technologies. Though often arising from unproven long-term performance of innovative systems, this conservatism is driven frequently by designer's actual or perceived expectations of clients' needs. Major clients are thus, by explicit communication of their wish for sustainable buildings, able to encourage the development and implementation of underlying technologies. Central and provincial government can be particularly successful in this activity, as they are often the largest clients. For example, in the 1970's and 1980's the UK central government's use of co-ordinated procurement based on performance specifications has been shown (Cheetham, 1997) to have reduced innovation market risks for the manufacturers of building components.

A particular technology will be a useful contributor to the overall sustainability of a building only for a specific set of contexts. The latter will vary depending on building use, location, climate, competing technologies, economic and social acceptability and regulatory imperatives. Selection must therefore commence with consideration of the broadest range of generic technologies on the basis of life-cycle environmental and economic analyses. In reality, seeking to produce buildings that are benign environmentally and viable economically is often a pragmatic qualitative process. For small projects the additional cost of further design work to attain more unequivocal sustainability is difficult to justify. The outcomes of pragmatic sustainable building design are often useful exemplars despite their inherent compromises (Skates et al, 1998). For those in developed countries, generic and technology-specific time-limited life-cycle analyses are available (see, for example, for solar water heaters, Smyth et al (2000)). For developing countries, not only are they not available, but the appropriate underlying public policy consensus is only now being developed. In particular in developing countries it is important, as noted by Muttagi (1998) that the pursuit of sustainability in buildings, and also in a wider context, does not reinforce economic disparities or instigate unwanted patterns of social change. The widest open participation in making underlying value judgements is thus essential. Vernacular or traditional building design solutions are frequently either inherently sustainable or the most sustainable within pertinent economic parameters. Where this is the case, in broad terms, the only additional technologies required are those that meet needs unsatisfied by traditional means.

Sustainable buildings are a contribution to the achievement of holistic environmental sustainability. There has, on occasion, been a tendency to pursue the goal of sustainable buildings through self-sufficient or autarkic solutions. Though such exercises are interesting, and often have considerable educational value, they do not, by their very nature, often address mainstream issues. After appropriate measures have been adopted to minimise building energy, decisions do need to be made as to whether energy will be produced at the building (by solar heating, photovoltaic, wind generation, etc) or purchased from utilities. Site factors, economic viability and environmental life-cycle analysis rarely combine to lead to a self-sufficient approach, rather an optimal mix emerges.

Domestic Examples
Consider the following specific examples of sustainable domestic buildings in the UK climate. They each subscribe to technologies that support sustainability including low heat-loss glazing set in the context of a passive solar design underpinned by best practice in energy conservation but in each case value judgements have been made with regard to the inclusion of additional technologies.

The Vale house at Southwell in Nottinghamshire, England sets out to be autonomous (Hawkes, 1995). The only connections to mains services are for telephone and a two-way electricity connection. The house design was predicted to rely only upon the resources of the land which it occupies. Among the many technologies employed are on-site rainwater collection and filtering for domestic use and a sewage composter for waste. A heat-recovery mechanical ventilation system is used to preheat incoming ventilation air and thirty-six photovoltaic 60-Watt panels largely meet electricity demand. These additional technologies combine to make the house autonomous thus achieving the design objectives, but they come at a price. The space required for the sustainable technologies accounts for approximately 30% of the floor area and represents a substantial initial cost overhead, in addition the photovoltaic array occupies a portion of otherwise useable garden space. This necessity of autonomy demanding so much space is a paradox in terms of sustainability. There are obvious limits to the density at which houses like this can be built with sufficient resources to meet their needs.

The Solar House in Magherafelt in Northern Ireland was designed to have a net carbon dioxide production from the site to zero, hence the acquired name “Zero $C0_2$ House” (Anon, 1996). The house is built on reclaimed land, and like the Vale house, uses low heat-loss glazing. It has high levels of thermal Insulation, uses heavyweight construction to provide high thermal mass and has a ventilation system with heat recovery. It also has wood burning facilities for heating using site grown timber (In the case of the Vale house the trees felled to make room for the house were not replanted and were thus a finite resource). This house too has grey-water recycling through a reed bed and pond system, but the water is only used for the garden and car washing. The inclusion of a single-phase mains parallel wind turbine is designed to meet demands for electricity consumption. In addition, the house makes use of evacuated heat pipe solar collectors for heating domestic hot water. All in all the cost of the additional sustainable technologies represents approximately 25% of the total building cost. Again this house meets the design objectives, but also like the Vale house, there are clear cut restrictions to replicating the Zero CO_2 House in the mass housing market.

The Skates' house in Antrim, Northern Ireland was designed with a pragmatic approach balancing affordability, buildability and sustainability with the main design aim being year round low cost thermal comfort (Skates et al, 1988; Skates and Norton, 2000). It too was built on reclaimed land and makes use of passive solar design principles. Like the previous examples it incorporates low heat-loss glazing, high levels of thermal insulation and mechanical ventilation with heat recovery, but instead of having high thermal mass, relies on a highly efficient fast response heating system to provide even annual and diurnal internal temperatures. Some spaces have been allocated to easily accessible service ducts to allow for the inclusion of additional sustainable technologies such as solar water heating and grey water recycling as they become attractive economically. The cost of building this house was on a par with traditional construction even though a number of innovative construction methods and materials were incorporated. Clearly there is significant potential to replicate and further refine this form of sustainable construction.

Low-Cost Concentrator Pv Façade

For photovoltaics to achieve wide scale implementation as a building façade cladding material it is essential that their cost is reduced while maintaining or exceeding present levels of performance. The use of concentration is one method by which a cost reduction may be achieved, however due to the restriction on tracking imposed by having façade mounted systems the level of concentration is limited to the range of 2.4 to 3.

Employing solar concentration with photovoltaics enables total system cost to be reduced per unit of energy delivered. Low concentration non-imaging systems do not require tracking. The potential to use such systems for cladding buildings combined with economies of scale resulting from increased volume of manufacture could enable the cost of a unit energy delivered to be reduced by up to 50%. The advantages of using low concentration non-imaging optical concentrators are that concentrations of up to 3 can be achieved without tracking while accepting all of the direct insolation and the majority of the diffuse insolation. The area of semiconductor material required for such a system may be reduced by up to two thirds. To achieve a large total system cost reduction it is essential that the reflector subsystem incurs marginal additional cost. Systems with concentrations in the range of 3 to 10 introduce a tracking requirement or have very curtailed collection periods.

A solid transparent dielectric-field concentrator, as shown in Figure 2, is fabricated from a glass or acrylic material with a refractive index of approximately 1.5. Refraction at the aperture to the concentrator enables the design concentration ratio to be increased to 3 while maintaining acceptance of all of the direct and 50% of the diffuse insolation. In contrast for a stationary non-refracting system, the maximum concentration ratio that can be achieved is 2, again with 50% of the diffuse collected. Solid dielectric concentrator systems can also be designed so that most light that enters the concentrator undergoes total internal reflection at the dielectric/air interface, with only minimal transmission optical losses. The dielectric system is better than a similar reflective system due to its high optical efficiency and greater reduction in PV area required while maintaining similar solar energy utilisation Using a low cost dielectric material enables significant cost reductions to be achieved. To minimise the weight of the concentrator panels and the quantity and thus cost of dielectric material, it is essential that the width of the photovoltaic cells is minimised. The limiting factors on size reduction ar the electrical efficiency of the photovoltaic cell reducing because of edge effects, and deterioration in optical efficiency of the concentrator due to errors in the manufactured reflector profile and mis-location of the photovoltaic cell.

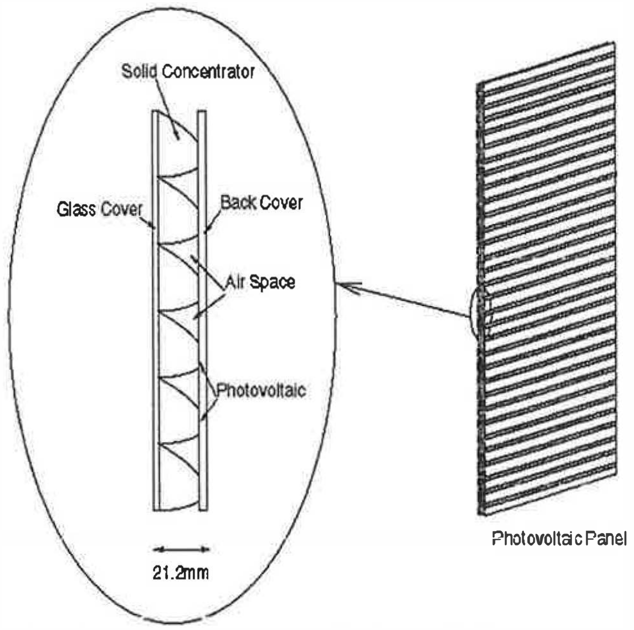

Figure 2 : Low-cost concentrator PV façade design

For the developed design shown in the diagram high levels of optical efficiency are achieved for insolation incident within the angular range between 2° and 65° from the perpendicular to the aperture surface. This particular geometry allows the concentrator to be mounted vertically at latitudes around 52°. For more southerly locations high levels of performance can be achieved by slightly inclining the panel. The depth of the concentrator and thus quantity of dielectric material required is linearly proportional to the width of the photovoltaic cell, for each mm width of the photovoltaic strip placed at the exit aperture of the designed concentrator, the required depth increases by 1.76mm. For a 3mm wide PV strip the concentrator element is 5.3mm deep and for a 9mm wide PV strip the concentrator element is 15.9mm deep.
In a three-dimensional optical analysis losses resulting from reflection of the insolation at the aperture to the concentrator along with transmission losses due to absorption within the solid dielectric material were included. The concentrator was assumed to be fabricated from an high transmittance dielectric acrylic material with an extinction coefficient of 4 m^{-1} and refractive index of 1.523, the concentrator was bonded to a sheet of low iron glass with similar optical properties. Total internal reflection with a 100% reflection efficiency occurs for all rays incident at the dielectric-air interface outside a 41.04° cone, rays incident within the cone are refracted and exit from the concentrator through the air-dielectric interface.

Combining details of the optical efficiency with direct and diffuse insolation data, predictions of the annual performance of the system in comparison to a flat plate system were made. The values given in Figure 3 are for the energy reaching the photovoltaic surface before conversion to electrical energy. Based on a square metre of aperture area for systems located in London with vertical orientation the predicted annual collected energy is 1749.1MJ for the concentrator and 1978MJ for a standard PV system. If a comparison is made based on a square metre of photovoltaic area the value of energy collected for the concentrator system becomes, 4320.9MJ i.e 2.18 times greater than that for an equivalent area of photovoltaic material in a flat PV system. For Crete; based on aperture area for a vertical orientation the value of annual collected energy is 2981.9MJ for the standard PV system and 2767.7MJ for the concentrator. If a similar comparison is made based on photovoltaic area the value for the concentrator system becomes, 6943.7MJ i.e. 2.32 times greater than that for an equivalent area of photovoltaic material in a flat PV system. The variation in perfomance results from the different diffuse fractions in the two locations.

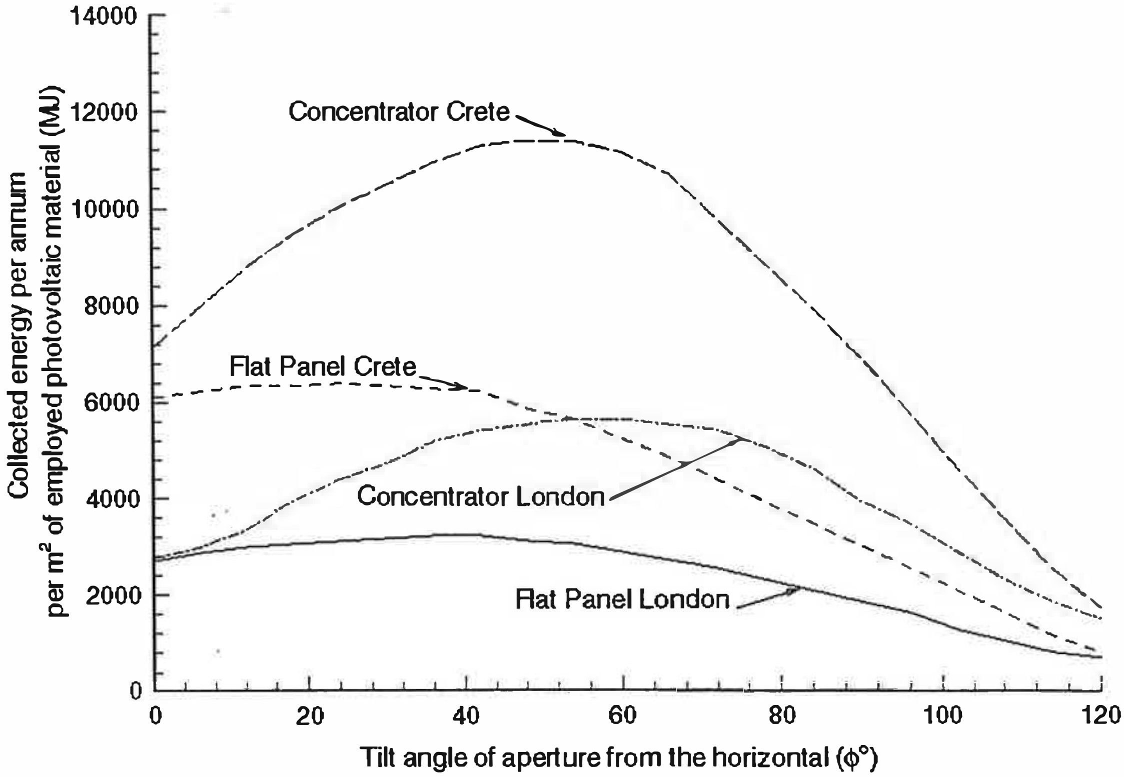

Figure 3 : Energy collection for a flat module and the low-cost concentrator PV façade installed in Crete and London

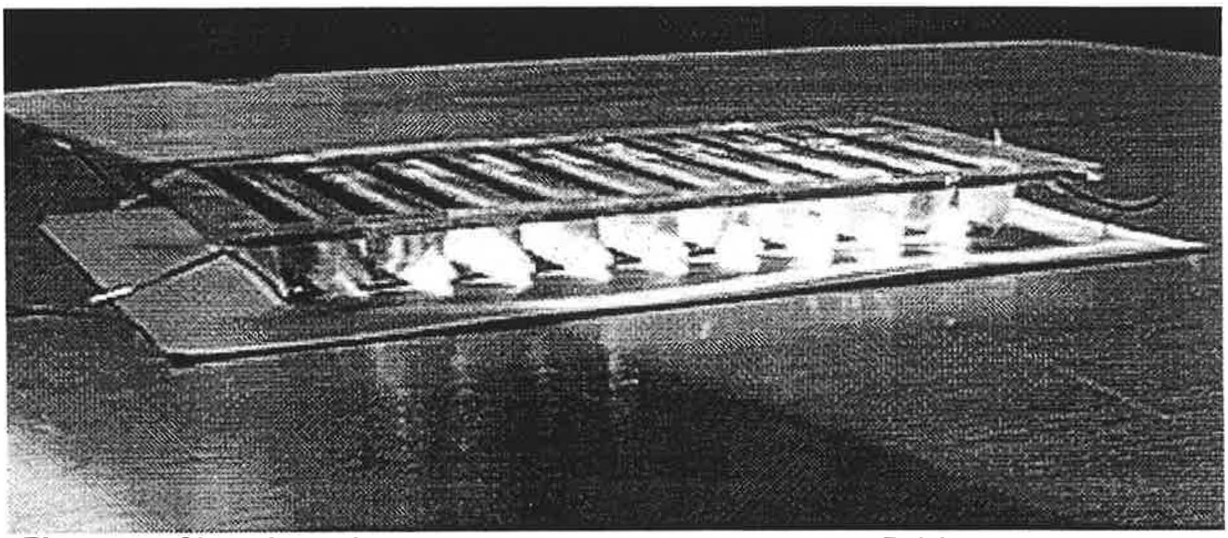

Figure 4 : Side view of prototype Low-cost concentrator PV façade element

The low-cost concentrator PV façade, as shown in Figure 4, was tested under a line-axis solar simulator with a collimated output to determine the variation of achieved concentration with solar incidence angle. The levels of concentration achieved approached those theoretically possible. At low angles of incidence corresponding to ground reflected radiation the experimental performance exceeded that predicted, due to radiation passing through the concentrator walls and reaching adjacent photovoltaic cells.

The approximate volume of dielectric required to produce a 1 by 0.6m panel consisting of five strings of the designed 2.46 concentration ratio PV system, is for 3, 6 and 9mm wide cells respectively 2.5, 5 and 7.5 litres. The cost of the dielectric used in large scale production extrapolating from small scale laboratory production may be down to £6.85 a litre giving dielectric costs for each system of £17.13, £34.25 and £51.38. Compared to the 36 wafers in a standard panel of 0.6m surface area, less than 15 would be required for the concentrator system. For it to be uneconomic to use the designed concentrator system, wafer costs would need to be less than £0.95, £1.85 or £2.78 for each system respectively. This assumes that the desired level of performance is achieved, i.e. a minimum 88% of the solar energy utilisation of a non-concentrating PV module and that production is in sufficient quantities so that the initial tooling and automated plant costs when amortised over large production volumes are negligible. The PV cost used for the predicted cost scenarios was £3.50 a wafer in the year 2000 reducing to 50% of this value over a ten year period.

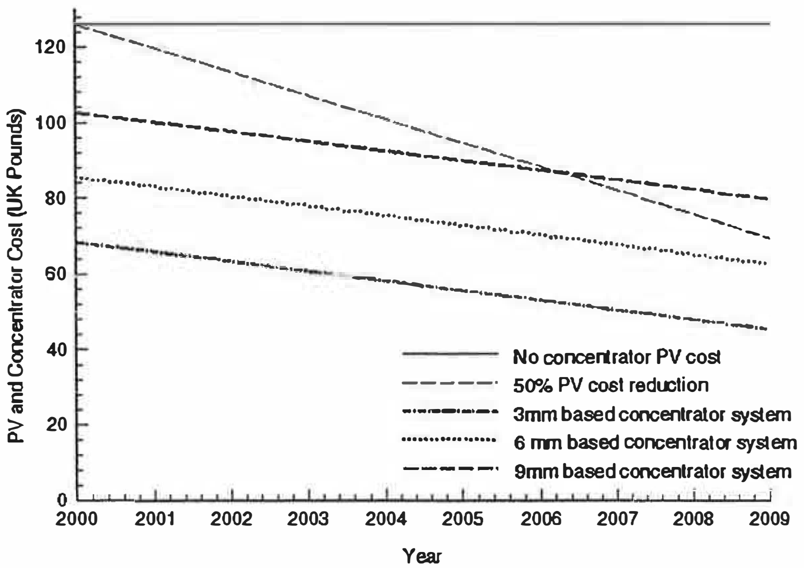

Figure 5 : Predicted cost scenarios for low-cost concentrator PV facade

Conclusion

The strategic Issues underlying the selection of appropriate technologies that contribute to the environmental sustainability of buildings are discussed. Specific examples of building technologies and the goal of achieving sustainability are described. Three sustainable houses in the UK are compared; each of which contributes in its own way to the achievement of holistic environmental sustainability. A novel photovoltaic façade has been discussed as an example of leading-edge technological innovation that seeks to contribute to the achievement of sustainable buildings.

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Auditing A City's Energy Consumption

M. Bennett and M. Newborough
Applied Energy Group
Cranfield University
Bedford
MK43 0AL
Tel. (01234) 754642

ABSTRACT

The auditing of energy use on a city-wide scale offers a route to achieving an improved understanding of energy utilisation and emissions at a devolved, locally-relevant level, thus enabling prospective consumption or emissions reduction actions to be prioritised effectively. A practicable methodology for auditing energy use in a city has been developed and the findings of a recent audit undertaken for the city of Peterborough are discussed. A framework for undertaking a national series of local audits is presented as a means for assessing consumption and emissions in different cities/towns, for facilitating the setting of realistic targets and, in due course, for confirming that such targets have been achieved. If implemented widely, regional and national policy makers could thereby obtain an improved quantitative picture of energy consumption/CO_2 emissions across urban Britain.

INTRODUCTION

In addition to the Kyoto agreement, the UK government is committed to achieving a 20% reduction in the annual rate of CO_2 emission (relative to 1990) by 2010. It aims to realise this through a combination of greater energy efficiency, increased use of combined heat and power (CHP) and renewable forms of power generation, and by developing an integrated transport system. In order to realise these CO_2 reductions, a more comprehensive understanding of the existing status and extent of energy consumption is required. This may be realised by auditing energy-use, for example by industry, product, household, end-use activity or community. A major consideration is that the audit's findings should facilitate identifying the changes required to meet emissions-reductions targets, and provide a basis for verifying future achievements. Thus, the audit should produce an output that is both comprehensive in its coverage and useful to different groups of users. (e.g. from individual households or businesses assessing their own consumption compared with say an average value, to governments formulating policies on a national level that are derived from sets of local data.)

The auditing of a city, or urban conurbation, is proposed as means for exposing the complexity of energy use at a scale that is well-suited to the processes of identifying, developing, implementing and monitoring effective emissions-reductions solutions. The methodology used is driven partly by the availability and accessibility of relevant data, rather than by a prescriptive sectoral/end-use framework. It is important to avoid producing a 'wish list' of data sets which cannot be completed practicably within a reasonable timescale. Such a 'data driven' audit will provide present and predicted energy consumption data for a given year (and the associated annual financial cost and emissions data) for the different sectors and sub-sectors of the city, and will allow areas of significant demand (and the associated opportunities for taking action) to be identified. It is considered that this approach of using local data to promote local action is more likely to be effective in devolving ownership of the emissions-reduction problem to those who need to act.

A major energy end use is transport, which accounts for ~25% of the UK's CO_2 emissions. At present, the majority of transport energy use is uniquely defined by combustion engines and petroleum-based fuels. To achieve a major reduction in this area, action is required at a macro/national level. While local action is feasible, it will have a limited sphere of influence due to the transient nature of the emissions production. Thus, although transport energy consumption may be considered within a city energy-audit, it is suggested that it is best dealt with as a separate issue.

THE AUDIT

An audit methodology is required that will yields the required information and provide a sufficiently detailed output within the limits of available resources. The first stage is to divide the city into a series of sectors and sub-sectors; domestic, industrial, shops, houses, etc. The relative importance of each sector, and thus the number of related sub-sectors assigned, should be based on an examination of preliminary data for the population, the number of domestic dwellings and the size of the industrial and commercial sectors, etc. This energy-use structure for a city is shown in Figure 1. Further sub-division should be carried out as a more detailed understanding of the available data becomes known, and continued until either the data source has been exhausted, or the agreed minimum level of definition has been reached. (e.g. each million pounds spent on energy within the city or each GWh consumed) This will structure the breakdown of the city into a series of logical groups and sub-groups to produce a set of smaller, more manageable tasks.

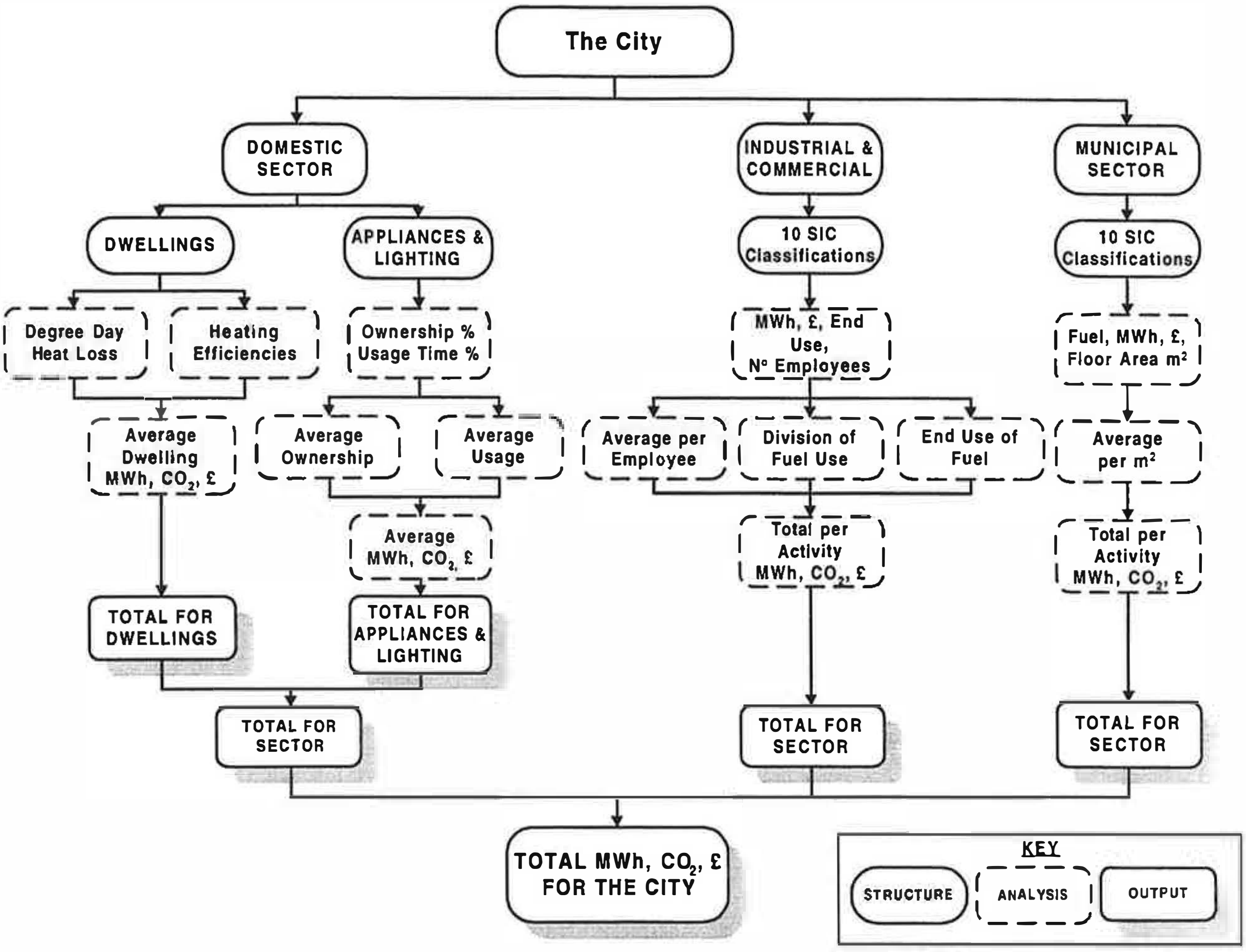

Figure 1 - Energy-Use Structure For A City *(SIC - Standard Industrial Classification the national and international standard for classifying business activities)*

Once the structure has been defined, the detailed data can be collected, analysed and extrapolated to provide the required estimate. Using existing data will: (i) ensure that the audit's base line is comparable with any existing analyses; (ii) facilitate links between the audit and local professionals working in energy related fields, and (iii) concentrate attention on less well-defined/quantified areas where existing data are lacking. Where little, or no, data are available, or where only macro data exist , it will be necessary to fill the gaps by developing estimates based on the findings of local surveys, mathematical models or end-use monitoring. Local surveys are essential to ensure that the results relate closely to the city under examination.

Having established the sub-sector and sector totals, values for the total energy consumption, cost and CO_2 emissions for the city can be estimated. The summation process tends to yield significant discrepancies, so a checking procedure is essential; this enables weaknesses in the data sets to be clarified and solutions for improving data quality to be developed. By undertaking a 'what if' parametric analysis of the sectors/sub-sectors/end-uses that are particularly influential, the auditor can establish where future attention should be focused.

The audit provides a numerical platform from which the energy-savings potential within the city can be estimated, however, the process of defining what needs to be done to realise any given target is not straightforward. From the findings of the audit the significant areas of consumption can be identified; whether a sub-sector or end-use activity is considered 'significant' will depend in part upon the level to which the analysis has been taken and the process of assigning significance is again not straightforward. By selecting, say, the three areas of greatest energy demand within each sector as being significant and worthy of attention, a focus on achieving a sense of local responsibility within all sectors is gained and the opportunities for attributing excess consumption to another party is diminished. Alternatively, it may be desirable to consider any consumption over a certain threshold as being significant. The downside to this method is that activities under the cut-off point could then believe that they need not concern themselves with energy efficiency. If the three areas of greatest consumption within each area are identified, then the idea that consumers from all sectors have a responsibility for energy consumption is reinforced. (accepting that the significant consumptions within the domestic sector may be considerably smaller.)

Once the 'significant' areas of consumption have been defined, the level of CO_2 savings can be estimated. There are two aspects to this. Firstly there are the absolute savings possible in a 'perfect world', obtained if best practice and best available technology reached 100% penetration throughout all areas. Then there are the actual savings that are likely to be made, which are functions of issues such as the availability of technology and the economic and human factors that influence the associated take-up rates.

The domestic sector profile (high levels of ownership of a limited number of appliance types) allows the savings potential to be calculated by identifying the most efficient models for each appliance type and then assuming these models to be in use throughout the city. In order to estimate the actual savings potential, the likely penetration rate of these efficient models must be examined. Penetration is dependent on many factors, including the cost and availability of the appliances, the lifetime of each type of appliance, and the existence of any incentive schemes. These factors can be defined with a fair degree of accuracy, while others relating to human nature are less readily quantifiable! Such human factors exacerbate the task of predicting take-up rates for the domestic sector. Therefore, the auditor may conclude that the take-up rate is best defined for the domestic sector as 'the rate at which savings will need to be achieved in order to meet a given target'.

Within the industrial and commercial sector there is a wide variety of equipment in use, which makes it difficult to define a list of best available technologies for estimating energy-saving potential. The industrial and commercial energy consumption has been defined by end-use for each sector, so the potential savings can be assigned on a similar basis. Accordingly the potential absolute savings are less rigorously defined as they have to apply to a wider range of equipment. Additional uncertainty will be provided by a set of business-related human factors, but the predominant issue is investment finance and the associated payback periods for implementing an energy-saving fix.

THE PETERBOROUGH ENERGY AUDIT

Peterborough, a city of approximately 160,000 people, 65,000 dwellings, and 2,800 business activities, was audited using the methodology outlined. The audit was managed by Peterborough Environment City Trust, and took place between November 1996 and March 1998. Much useful housing data was obtained from the city council and a domestic survey of local householders (with >500 respondents) provided data for domestic appliance ownership and use. A business survey, based on 300 face-to-face interviews

and a postal survey, was conducted to obtain data for the industrial and commercial sector. Other assistance was provided by a number of business organisations and local groups, and use was also made of data obtained from sources of national statistics.
The audit revealed an estimated total annual end-use energy consumption for the city of 3.2 million MWh, which was provided at a delivered cost of £75 million and resulted in the emission of 1.6 million tonnes of CO_2. The energy consumption and resulting emissions were split approximately one third domestic and two thirds industrial and commercial. However, due to the relatively low unit energy prices applying in the business sector, the total spend was divided almost equally between the sectors.

The Domestic Sector

Domestic sector consumption was dominated by a large space and water heating demand, (approximately 75% of the domestic total), which was met mainly by natural gas. Peterborough is a relatively new city, 55% of its dwellings having been built since 1965 compared to a national average of 22%. Hence much of the housing stock is of a reasonable energy-efficiency standard and gas fired central-heating systems predominate - the fuel consumption by age and type of dwelling is shown in Fig 2. It is interesting to note that the post-1965 houses account for 42% of the total space heating requirement.

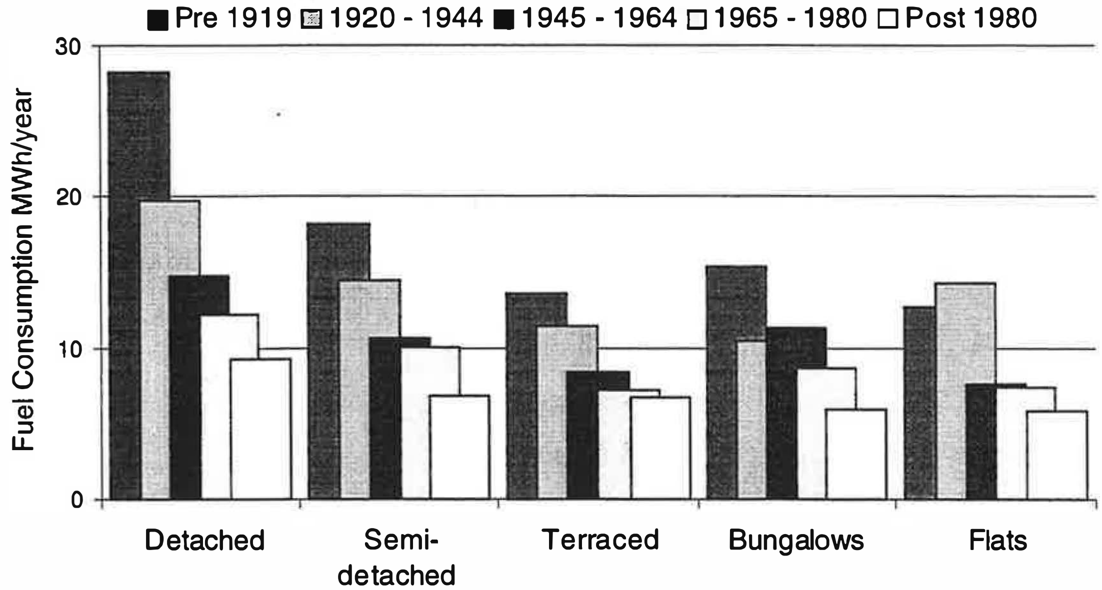

Figure 2 - Predicted Space Heating Requirements by Dwelling Age and Type.

The greatest single electrical loads were found to be refrigeration, washing appliances, and lighting, comprising 7%, 4%, and 4% of the domestic energy demand, as shown in Table 1. The estimated refrigeration load was larger than expected, as the domestic survey revealed an average ownership level of 2.0 refrigeration appliances per household, which is higher than has been reported elsewhere.

Domestic Sector	Fuel Consumption (% Domestic Total)	CO_2 Emissions (% Domestic Total)
Space Heating	55%	36%
Hot Water	20%	7%
Refrigeration	7%	15%
Lighting	5%	16%
Cooking	4%	7%
'Wet' Appliances	4%	8%
Television & Video	2%	5%
Supplementary Heating	2%	3%
Small Loads	1%	3%

Table 1 - Breakdown of Domestic Consumption and CO_2 Emissions.

The Industrial and Commercial Sector

There are three features of Peterborough's business community that help to define it's energy consumption.

- Peterborough is a major retail centre, with a large shopping area that attracts 13 million shopping visits per year, with 500,000 potential consumers within 35 minutes travel time
- Peterborough is the home to the headquarters of several large national companies, including travel and insurance businesses
- Peterborough has a declining, but still significant, engineering sector employing 10% of the workforce

The Distribution and Catering sector accounted for approximately 21% of the industrial and commercial energy consumption, followed by Manufacturing, 19%, and Engineering with 17%. These values emphasise the energy intensive nature of the manufacturing sector; the energy spend per employee in the manufacturing sector was four times that of the distribution and catering sector. The breakdown between the sectors is shown in Table 2.

Industrial and Commercial Sector (By SIC Code)	Fuel Consumption (% Industrial and Commercial Total)	CO_2 Emissions (% Industrial and Commercial Total)
0 Agriculture	9%	11%
1 Energy & Water Supply	7%	10%
2+3 Chemicals, Metals & Manufacturing	17%	19%
4 'Other' Manufacturing	19%	19%
5 Construction	2%	2%
6 Distribution, Catering, & Repairs	21%	19%
7 Transport & Communications	9%	7%
8 Banking & Finance	9%	7%
9 'Other' Services	7%	6%

Table 2 - Breakdown of Industrial and Commercial Consumption and Emissions.

('Agriculture' and 'Energy & Water Supply' excluded due to small data sets)

Within the industrial and commercial sector the overall division between fuels was found to be electricity 33%, gas 40%, oil 5%, with the remaining 22% of consumption being described as 'Other'. This term was employed to describe energy that was consumed by the sample, but that had not been ascribed to any of the three main fuels - this was usually due to uncertainty or poor record keeping on the part of the surveyed companies. Analysis of the final end use showed that approximately 22% of the industrial and commercial total was associated with lighting, including 7% within the retail sector alone. A further 14% was used to meet the space heating requirements, including 4% within the retail sector. An example of the breakdown of the electricity end-usage is shown in Figure 3.

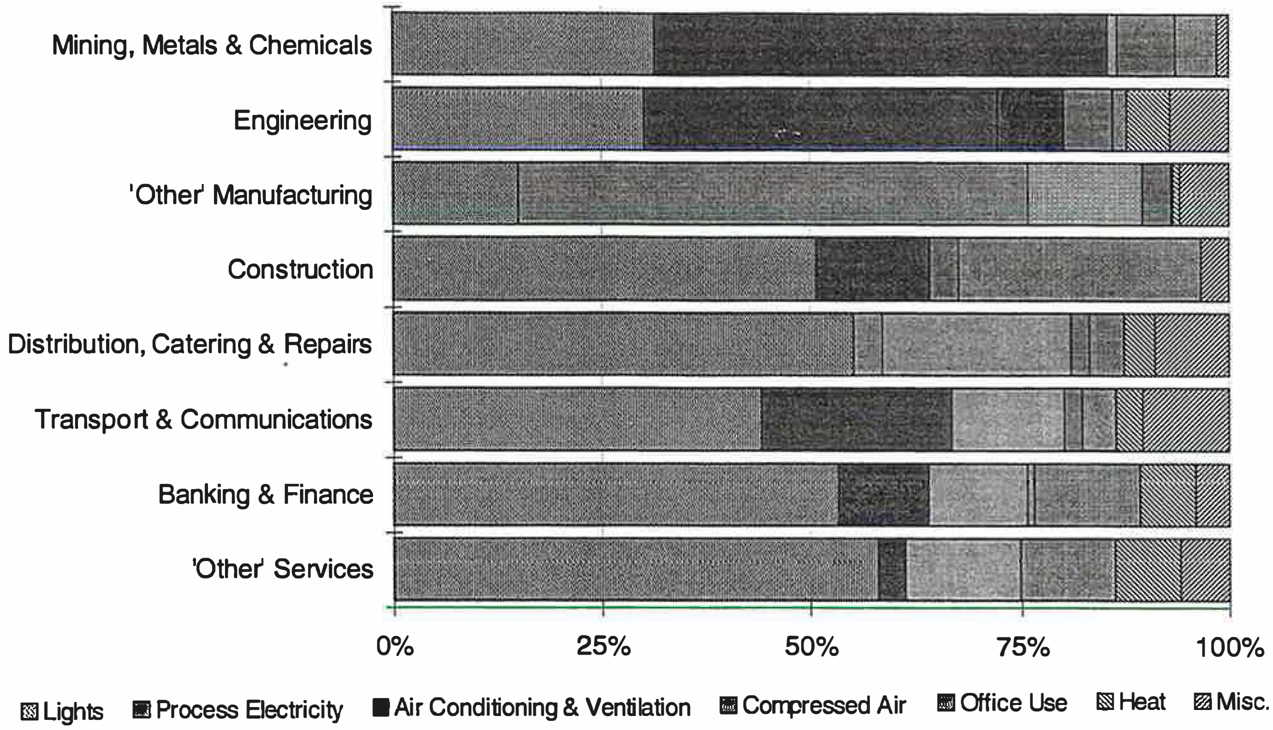

Figure 3 - Breakdown of Industrial and Commercial Electricity End-Use. *('Agriculture' and 'Energy & Water Supply' excluded due to small data sets)*

CO_2 Emissions and the Targets

The total rate of CO_2 emissions were quantified for Peterborough from the estimated energy consumption - see Figure 4.

A set of targets that illustrated how Peterborough might achieve an overall 20% reduction in CO_2 emissions was constructed by applying current best available practice to the areas of greatest energy demand within the two sectors. For the domestic sector, a 50% take-up (replace half of the 'not best practice' items over ten years) of efficient condensing boilers with appropriate controls, efficient refrigeration appliances (rated A or B on the current EU energy label) and compact fluorescent lighting would yield a reduction of approximately 25% in CO_2 emissions from the domestic sector. For the industrial and commercial sector, where there is a greater variety of equipment in use, the possible savings were identified by fuel type. Savings of 25%, 30% and 20% for electricity, gas and oil consumption were applied to the areas of greatest demand, with take-up rates of 20%, 25% and 15% respectively. The resulting reduction was estimated to amount to approximately 16% of current CO_2 emissions from the industrial and commercial sector.

Proportionally greater savings appear to be available in the domestic sector, but this is partly due to the various end-use technologies being more readily identifiable. Thus, in the domestic sector, an educational approach of 'Do X to Y', or 'Replace old Z with new Z' can effectively promote the energy-efficiency/emissions-reduction message, whereas in the industrial and commercial sector, it may be necessary to examine individual sites in detail in order to identify the correct X to be done to Y, or the exact type of new Z to replace old Z.

Peterborough Environment City Trust has now initiated a consultation process through which the means to implement the targets will be identified. A series of brainstorming sessions have been undertaken in conjunction with local interested parties to identify these strategies and these are now in the process of being put into action.

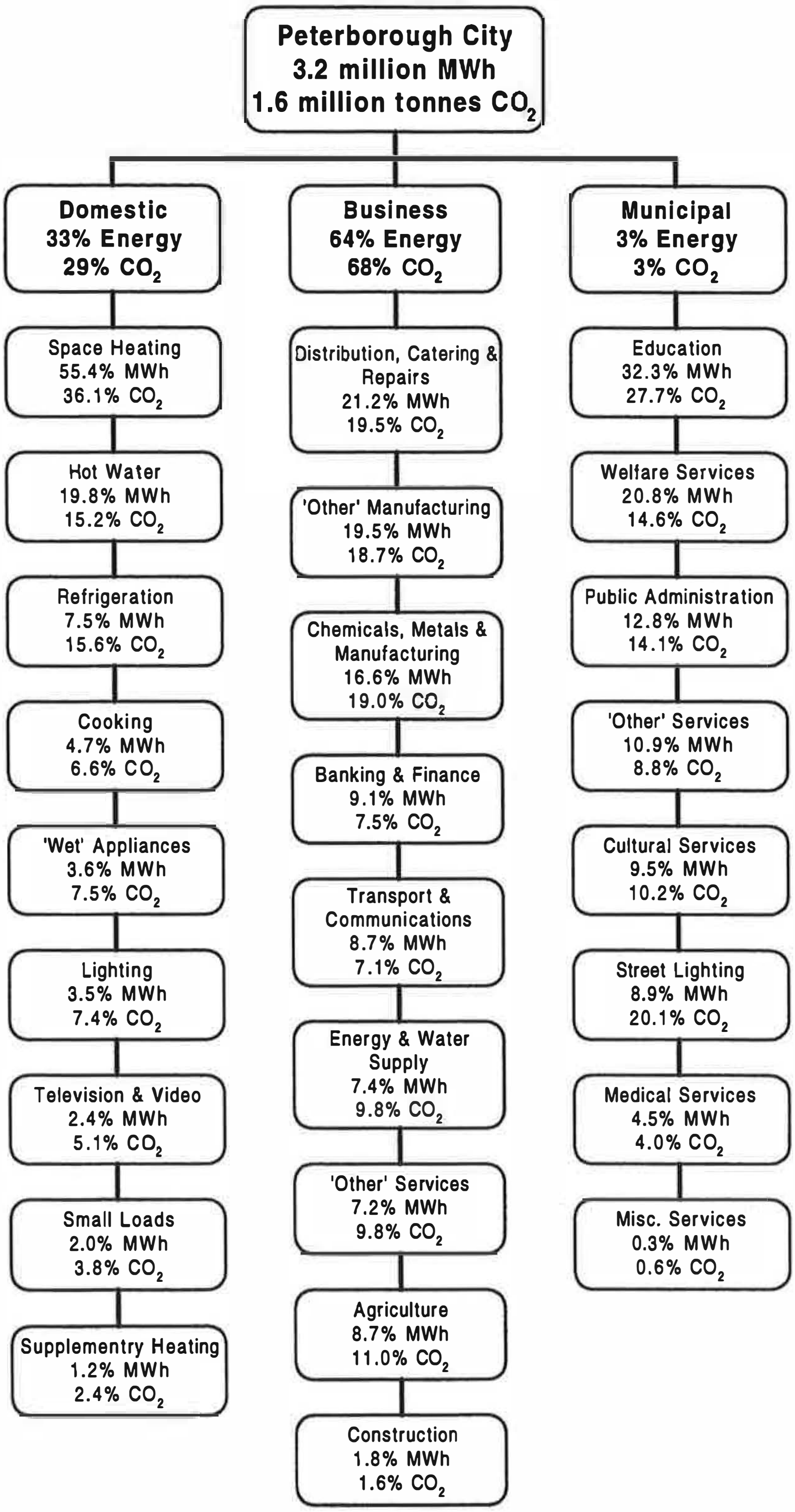

Figure 4 - Overall Distribution of Consumption and Emissions For Peterborough.

A NATIONAL FRAMEWORK FOR CITY ENERGY AUDITS

Consideration should be given to applying the city auditing process to several major UK cities or urban conurbations - if the twenty largest cities (including Greater London) were audited, the coverage would equate to 25% of the UK population. Each urban area would gain a well-focussed local data set and benefit from the experience of the other audits. In addition, the individual sets of results could be combined to form a macro (regional or national) picture, in order to clarify which end-uses might best be addressed/co-ordinated nationally and/or locally.

Although the audits should be driven by individual cities, it is desirable to undertake compatible studies in order to facilitate compilations and comparisons at regional. It is therefore recommended that a national framework be developed for carrying out city audits, which also permits the individual audits to undertake locally-relevant work. This framework should include the definition of:

- The breakdown of the city into its sectors, sub-sectors and further sub-divisions.
- The specifications for undertaking domestic and business surveys.
- A model for predicting domestic space heating requirements.
- A structure to report the audit results.
- Suitable indicators as a basis for target setting.
- A requirement to identify the areas of significant consumption within each sector, the savings potential and routes towards achieving them within a specified period.

The RDAs are well placed to oversee the implementation of such a series of city energy audits. Within the strategic aims of central government, an RDA could oversee the implementation of audits in selected cities within its region. Although cities within a region may share some characteristics, contact between the RDAs across England could help identify similarities in energy use between cities and speed the implementation of local energy-efficiency/emissions-abatement action.

An outline structure for implementing a series of city audits is illustrated in Figure 5. It is considered that, given this type of structure and level of government support, it should be feasible to complete the audit and initial output within a period of eighteen months. The task of disseminating the advice, forming partnerships and implementing energy efficiency projects would then continue and it may well take a further twelve months to initiate effective local actions aimed at achieving the priority targets identified by the audit. To assure long term success post-audit mechanisms should be introduced to confirm that progress is being made towards the CO_2 reduction targets.

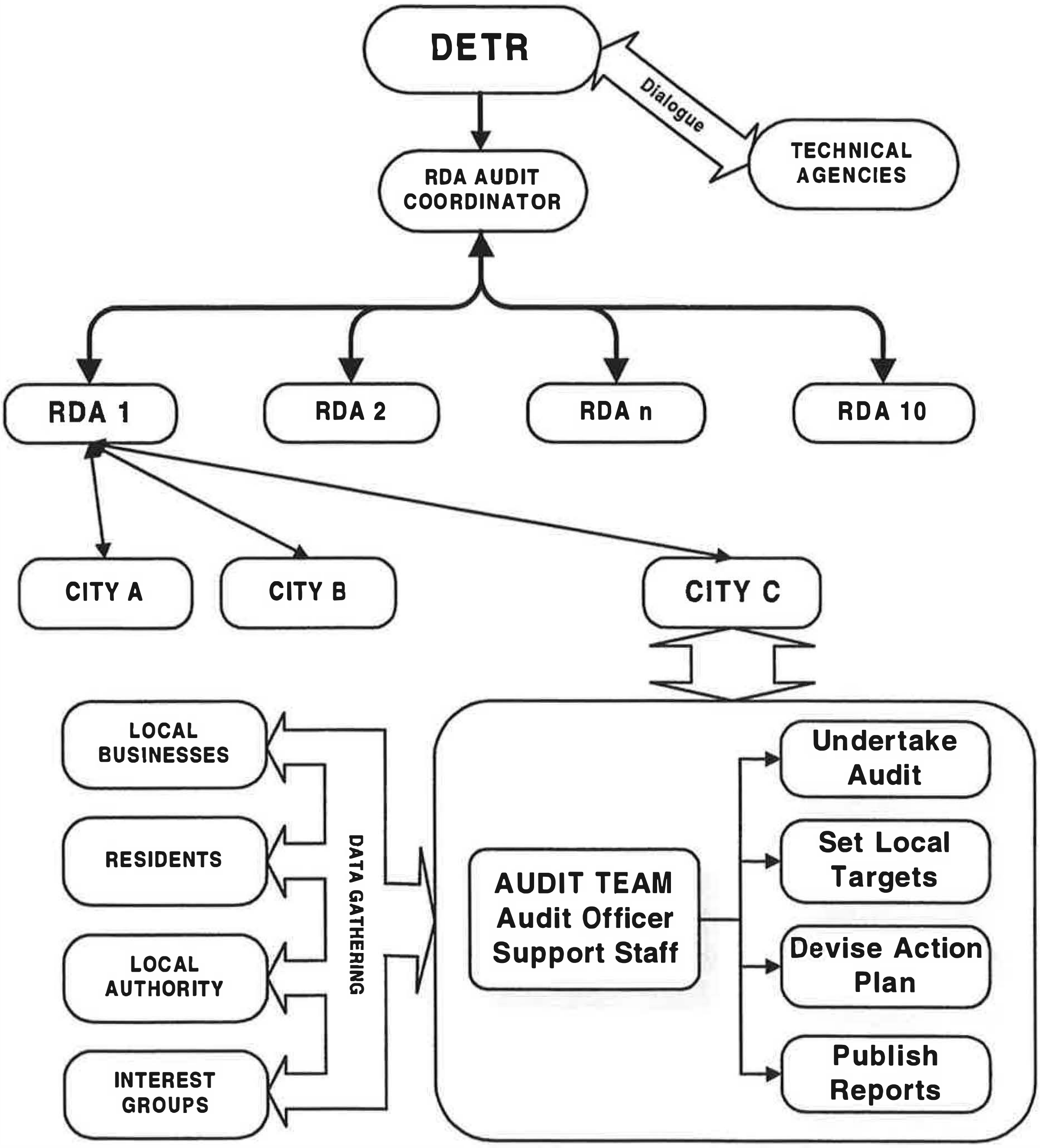

Figure 5 : System Structure for National Coverage of Energy Audits.

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Renewable Energy for Cities: Dreams and Realities

Dr D. Elliott with Dr D. Taylor

ENERGY AND ENVIRONMENT RESEARCH UNIT, THE OPEN UNIVERSITY

It is fashionable in some circles in the UK these days to see rural economies as in need of subsidies. However, the reality is that the 70% or so of people who live in urban areas rely on rural resources for many of their basic necessities- most obviously food, but also water and energy. So, in effect, cities are dependants - even parasitic. To put it in contemporary terms, their ecological footprint, that is the area of land that would be needed to support them and deal with their wastes, is many times the land areas they actually cover. For example the footprint for London is about 125 times the area of the city, and equivalent to nearly all the UK's productive land area (1).

One type of response to this sort of analysis is to call for the break-up of cities and a shift back to decentralised living. Realistically however, there is no way that the huge urban populations could be dispersed, especially in a small island like the UK. In any case, there are some technical advantages and operational efficiencies from urban concentration, quite apart from the cultural attractions of metropolitan living, and the fact that the existence of cities means that we still have areas of undeveloped landscapes. More to the point, perhaps surprisingly, it could be that technological developments may make it possible for cities to become more self-sufficient, at least in terms of energy.

In this paper, I want first to sketch out the lines of the emerging 'sustainable city' vision, focusing on energy. My emphasis will be on energy use in buildings, which is responsible for around half the UK's current carbon dioxide emissions. Then I will go on to look critically at some current UK examples of practice on the ground - the reality behind the vision.

The Sustainable City Dream

Focusing just on energy, it is now sometimes argued that, far from being a major energy drain, cities could meet a substantial part of their energy needs from their own energy resources, without adding to the problem of Climate Change, by using renewable energy sources. In the past, energy has usually been brought in to cities, from remote and usually polluting power stations, by wire or pipe. However, there are now technologies available that can use clean renewable energy sources which are directly available in cities, **solar photovoltaic** (PV) technology being the most obvious.

Cities actually offer an ideal location for the installation of solar PV modules. For example it has been estimated that, if PV arrays were mounted on suitable south facing roof tops and facades in a city like London, they would have a total generating capacity similar to that of around two conventional power stations (2).

Of course, there are draw-backs with solar PV. Solar energy is not available continuously, especially not at night! Never the less, some types of urban energy use are well matched to solar energy availability, most obviously day time office electrical loads and, in particular, summer time air conditioning loads. In addition, if power from PV arrays is fed into national power grid, low levels of solar energy availability in one location can to some extent be compensated by excess solar energy available in other areas, with the grid acting as a buffer, balancing out local variations

However, if power from PV arrays can be stored in some way, then of course, the solar options widen. The most obvious storage route is to use electricity from PV arrays to electrolyse water to generate hydrogen gas. Hydrogen can be stored and transmitted down pipes and used where and when needed, either for direct heating, as a combustible fuel, or in a fuel cell, to generate electricity. It can also be used as a fuel for vehicles, either directly or via a fuel cell.

PV is of course still expensive. Currently PV arrays on a typical domestic roof costs something like £20,000 and will only offer a few kW of generating capacity. Enough, on average over the year, for lights and most other domestic electrical systems, but not enough for major loads like heating. However, usually such systems are linked to the grid and extra can be imported when needed, with any excess power being exported, thus potentially reducing overall electricity bills. Sadly, at present the electricity companies typically only pay as little as 2p/kWh for power sold to them and charge up to 7p/kWh for power bought from them. So PV is not very attractive to many people.

However, matters should improve. Firstly, PV cells are getting cheaper. As and when demand for them rises, their price should drop dramatically. One study suggested that given the creation of a reasonable market, PV would become competitive with conventional sources (3). Secondly, there is pressure on electricity companies to accept the idea of 'net metering'. Consumers who are able to export some power themselves would then only be charged, at reasonable rates, for the net amount of power transferred. One company (Eastern, now part of TXU Europe) is now offering this option. In addition, the full VAT charge has now been removed on professionally installed solar systems, including PV, so there should be more of an incentive to invest in this technology.

At present however, those people who have installed PV arrays on their houses in the UK, such Jeremy Leggett in Kew (retrofitted) and Susan Roaf in Oxford (newbuild), have done it as a demonstration of what can be done technically, rather than as an economically attractive investment. Never the less they do report that their electricity bills are now very small if not at times negative, and Sue Roaf runs a small electric vehicle from her house power (4).

The economics of PV also need to be set in a wider context. A modern integrated PV roof, made up of solar PV tiles, can substitute for an ordinary roof, so some of the cost of the PV system is offset, and this cost will in any case be offset by the value of the power generated. What other building item will actually earn it's keep? This same argument concerning costs has also been used on a wider scale. Prestige corporate headquarters office buildings often have vastly expensive facades of marble. A PV array could add the same glamour at around the same cost, but also generate power (5).

So far I've focused on PV solar for electricity generation, but there are other urban solar options, most obviously **direct solar heat collection**, for space and/or water heating. London has around 200 solar house projects, many of them the legacy of the old GLC/ South London Consortium days (6), and there are some 40,000 water heating systems installed around the UK. Passive solar design has subsequently become common in many new buildings, as a cost effective design option. Typically this can cut fuel bills by up to 30% over an average year. In addition there are of course a whole host of other ways to improve the energy efficiency of buildings, by good design of the body shell, proper insulation levels and the use of low energy appliances and domestic systems. The potential for energy saving is considerable, and as buildings become more energy efficient, then it becomes easier to supply their reduced energy needs from renewable sources.

Direct solar energy is of course only one of the renewable energy options available in cities. Cities also generate huge amounts of **domestic and commercial wastes**, which have a high calorific value, most of which is derived ultimately from solar energy. The first step should of course be to try to reduce the amount of waste produced, at source and then by composting, and recycling, but even so, cities are still likely to produce large amounts of waste, and it seems sensible to try to recover the energy from the non-recyclable waste that is left.

Recovering energy via waste combustion is not always popular, given fears about toxic emissions, and there are limits to the number of landfill sites we can accommodate near to cities, even if the methane gas they produce is tapped and used to generate power. Rightly or wrongly (and I'm from the former camp) fears about dioxin emissions from poorly run incineration plants continue to plague waste combustion projects.
One possibility is to move to pyrolysis, which seems to have fewer problems. Even less problematic is the well established technology of sewage gas combustion, and sewage is one resource cites have in plenty.

Of course all combustion processes inevitably generate carbon dioxide, a 'greenhouse' gas which contributes to Climate Change. However, recovering energy by waste combustion is at least partly greenhouse neutral, in that most of the original material is biological, and carbon dioxide was absorbed in its production. As for landfill gas, while there can be problems with toxic leachates, since we do have landfill sites, it is surely better to capture methane from them, rather than letting it escape into the atmosphere. It is a very powerful greenhouse gas.

Whether or not you view it as strictly renewable, the use of domestic and commercial wastes as a fuel is currently very commercially attractive. It becomes even more interesting if it is linked with co-generation- that is using the heat produced as well as the electricity, in **Combined Heat and Power** (CHP) Plants. They can more than double the overall efficiency of energy use, and small local CHP plants can feed heat to local district heating networks. But CHP and district heating really comes in to its own if use can be made of natural biomass as a fuel rather than wastes. Cities may not seem like an obvious source of biomass, but most cites do generate surprising amount of wood wastes from parks and the like, and some energy crops might be grown on brownfield sites.

Some modern low density cities, like Milton Keynes, should have sufficient woodland and parkland wastes to run sizeable power plants. We are working on a wood waste fired system for the OU.

CHP plants do not have to be large. Whereas in the past there have been plans for city wide CHP/district heating systems, these days the emphasis is on smaller units meeting local heat loads. Indeed some people even think we could move to domestic scale units, with these eventually being run off renewably-produced hydrogen gas, piped down a gas main, but with natural gas being used in the interim.

The bottom line, in my quick sketch of the main urban energy options, is that, given sensible attention to building design and the efficient use of energy in low energy devices and appliances, energy, demand could be cut significantly and renewables could make a significant contribution. For example, studies of Leicester carried out by the OU Energy and Environment Research Unit, suggested that demand could be cut by at least 60%, and much of this reduced energy requirement could then be met by CHP plants and from locally available renewable sources, with renewables supplying perhaps around 25% of the cities power. As a result, by 2020, Leicester's CO_2 emissions could be cut by 80% on 1990 levels (7).

However, this analysis does not exhaust the possibilities for urban renewables. In some cities, there are also other opportunities for using renewable sources, for example, **micro-hydro** projects on small rivers and even streams. One such project is underway on the River Wandle in S. London. Another option available in some locations is **geothermal** energy. Although not strictly renewable, heat can be extracted from aquifers and fed to district heating networks, as has been done in central Southampton. More generally, and without geographic constraints, use can be made of ground source heat pumps for heating buildings. By contrast, the prospects for the use of locally generated **wave** and **tidal** power directly in cites are limited, since the main wave resource is in remote areas offshore and few cites are on rivers with significant tidal ranges. However, in some locations it might be possible to use power from small onshore wave energy units or tidal stream generators in estuaries.

Finally, to complete my review of novel renewable sources, what about **wind** power? So far, wind power has been seen as pretty much irrelevant in urban contexts. Wind speeds are usually too low and finding acceptable sites almost impossible. However, a colleague at the OU, Dr Derek Taylor, is developing a novel building integrated wind turbine system which fits into the roof space of a house, the Aeolian roof. This takes advantage of the fact that wind speeds can be increased by appropriately shaped roof designs. Assuming that noise and vibration problems can be avoided, we may yet see wind power make an urban contribution (8). See Box 1.

Box 1 WIND ENERGY FOR CITIES Derek Taylor

It has been the accepted wisdom that wind energy is not practical in the urban environment, however that may not always be the case.

One option may be to have a 'ring of wind turbines' around towns and cities. If they are supplying customers in the city who are prepared to purchase electricity from a local company then this may be feasible. It may also be possible to utilise wind energy at urban open sites (e.g. school, college, hospital, council campuses and leisure sites and parks) which include low rise buildings. Similarly for open urban industrial, commercial and retail sites (eg. Blue Water in Kent). Dunkirk has a row of medium scale wind turbines along the sea front in the town. The Wood Green Animal shelter in Cambridgeshire has had a wind turbine in the centre of its site, adjacent to residential accommodation and animal enclosures operating since the early 1990s. A medium scale wind turbine was installed across the street from houses at the Earth Balance Centre in Northumberland. The 1.5 MW wind turbine at Swaffham in Norfolk has been successfully operating at an eco centre and similar tall wind turbines could be located in or near urban environments.

The viability of wind turbines may also not be so tightly linked to high annual mean wind speeds as was previously the case. For example some 4,400 MW of wind energy capacity has been installed in Germany (compared to around 350 MW in the UK) which has annual mean wind speeds comparable to the south east of England. If wind turbines are installed to generate electricity for the owner then the production offsets the electricity from the supplier. In addition excess electricity can be sold to green electricity companies. Alternatively it would be potentially possible to have net metering arrangements to facilitate the use of the electricity grid as a virtual energy storage bank.

It could be feasible to fund wind power now in some urban contexts, by adding a certain amount to the cost of each house, so as to contribute to the cost of a wind turbine which provides electricity to the community. Any excess could be exported and could potentially be part of a net metering scheme, with the revenue used to fund PV on the houses.

In addition to utilising conventional wind turbines there may be opportunities in utilising buildings themselves as wind energy harvesters. The author has invented and patented a family of planar concentrators (*Aeolian planar concentrators*™) which offer the potential to enhance wind speeds and as such should be well suited to the built environment. Some of the devices can be free standing (*Aeolian Sails*™) but some (*Aeolian Roof* ™and *Aeolian Towers™*) utilise appropriately shaped building surfaces to accelerate and direct the wind flow. The *Aeolian Roof* consists of a pitched, curved, membrane or vaulted roof to which is attached an aerofoil shaped concentrator parallel to and located half a metre or more above the ridge or highest region of the roof. In the gap between the aerofoil and the ridge are located small wind turbines (either cross or axial flow) which extract energy from the wind. The combination of aerofoil and roof shape accelerates the wind and wind speed even a slight increase in wind speed can result in a significant increase in power output. The *Aeolian Tower* works in a similar way to the *Aeolian Roof* except that in this case the arrangement is attached vertically parallel to the corner of a tall building with the gap between the aerofoil and the building aligned with comer of the building. In either case the aerofoils utilised can be *Aeolian SolAirfoils*™ which incorporate photovoltaic solar cells or other solar energy devices on or within the aerofoil itself.

Combining the *Aeolian planar concentrators* with solar energy converters offers the potential for almost year round energy production, because, whilst the level of solar energy is greater in the summer months and lower in the winter months, the reverse tends to be true for wind energy in the UK climate. And of course wind energy can also be available during the night. By combining output from the Aeolian Roof during the winter months with another geographically distributed form of ambient energy - that of the heat of the ground by utilising plastic circulation pipes (either in a borehole or a trench) - by means of a ground source heat pump, then this can be an efficient source of heating or hot water during the winter months. In the summer months the process can be used as means of cooling the building either by circulating water at ambient ground temperature (as is used in the BRE's Environmental Office) or by utilising solar electricity to drive the same heat pump to cool the building.

Including wind power with the other novel renewable energy sources I have outlined above, it may very well be possible that, in some situations, the contribution from urban renewable energy sources could rise well beyond the 25% suggested above. Moreover, assuming continued improvements in the efficiency of energy use in buildings and elsewhere, and the integration of energy efficiency and energy conservation systems with advanced renewable technologies, such as renewably powered hydrogen fuel cell systems, then the urban renewables contribution could rise much higher.

However, total urban self-sufficiency seems unlikely. So, the rest of the power required would have to be imported from rural areas - from remote windfarms, hydroelectric projects, offshore wave energy devices, tidal stream devices and so on. Some of the energy from these non-urban sources would of course be best used locally, and that is especially true of locally grown energy crops. But there should be sufficient extra, in time, to supply the cities.

The governments current overall target is to obtain 10% of the UK's electricity from renewables by 2010, and possibly 20% by 2025, but that could well be exceeded. Certainly, several countries elsewhere in Europe are already doing better than that. For example, Austria and Sweden both obtain around 25% of their total energy (not just electricity) from renewable sources.

The longer term prospects for renewables certainly looks good. The Shell global scenario suggests that renewables could be supplying around 50% of world energy by 2060 or so (9), while the World Energy Councils ecological scenario suggests that, if need be, we could move to a contribution of over 80% from renewables by 2100 (10). Ultimately, then, it is conceivable that we could, if we wanted to, move to a world economy based mainly on the use of renewables- including the energy used in cities. That was certainly the conclusion of the fossil-free global energy scenario produced for Greenpeace (11). The message was that renewables could in principle help us to reach a sustainable future. All that was needed was practical application and the political will.

The Practical Reality

There is inevitably a gap between vision and reality, and my critical comments below should not be taken as denying the possibility of change. Indeed they are offered in the hope that improvements will occur, so that we can move towards the vision.

Our first port of call is where I live and work - Milton Keynes- which is the home of several major experiments in sustainable urban development, including more that 300 solar/low energy houses (12). Initially most of these were public sector projects, like the 177 passive solar houses on the Pennyland estate built in 1980-81, but subsequently there have been three major commercial exhibition sites for demonstration housing projects, with a strong emphasis on energy efficient design and the use of environmentally sound energy sources.

Homeworld was the first, in 1981, then came Energy World in 1986 and finally Future World in 1994. Each site had its share of exotic designs- earth sheltered roundhouses, wind powered houses, PV assisted houses and so on, plus houses with a range of more conventional solar heating and energy efficiency features. Many were large, very up - market £200,000, (at today's prices) plus 'executive' style buildings- although there were a few so called 'social' housing projects, and some cheaper 'starter' homes.

A lot of publicity was generated when the sites were opened and large numbers of people visited to take a look. Afterwards the houses were sold off privately and interest has faded. But what is important for our purposes, is how successful have they been in energy terms in the years since completion? And, perhaps more importantly, what have they been like to live in? After all there is no point in developing exciting new low energy/solar houses if people hate them.

Architects seldom seem to go back to see how their creations have fared, but my colleague at the OU, Tam Dougan, decided to look at these three exhibition sites, and at the earlier Solar Court project, and to ask residents what they felt about the performance of their experimental houses. Her conclusions, based on a questionnaire administered to a sample of houses backed up by some interviews, have been published elsewhere, so I will simply pick out some of the highlights relevant to the present discussion (13).

Basically most of the resident liked the houses, and were keen on the energy saving features, but many of them had complaints about how the projects had been executed, finished and subsequently maintained. The main problem seems to have been that, as demonstration projects, many of the houses had been put up in a hurry and in some cases experimental systems were installed, kept running for the period of the display, but subsequently did not work properly. In some cases there had been some glaring botches, in others suppliers of exotic systems had since gone into liquidation, so residents could not get repairs made.

Some of these problems are just the outcome you might accept as inevitable from demonstration projects. But there are also some general lessons for sustainable housing development. The most important is that there is a tendency to install eye catching gadgets rather than deal with the basic issue of energy retention by the building envelop. Energy management devices that improve energy efficiency can obviously be sensible, but they can sometimes be very complicated, and , in practice it often seems to be the case that consumers do not know how to use them properly. Even simple central heating controls are often not used correctly. Never the less, consumers do initially seem to like gadgets and they make houses easier to sell.

There was more than a hint of this gadget fetish in the subsequent Integer House programme, the prototype for which was built at the Building Research Establishment at Garston. In addition to the various now - conventional energy saving features, such as passive solar design, this advanced building utilises state of the art telecoms and control systems to manage the buildings services. However, there are some automatic controls (e.g. occupation sensing lights), so, in this case, residents were relieved of responsibility for running at least some of the systems (14). But, quite apart from the problem of correct use, gadgets can go wrong and need to be carefully maintained to retain their energy saving capacity. That was one of the sad lessons learnt form some of the public sector active solar house projects that emerged in the 1970s. As public funds became scarce in the 1980s, maintenance schedules withered and performance decreased.

Moving up to date, the Milton Keynes survey found that many of the technological energy saving gadgets had been dispensed with, not because they weren't efficient, but because there was not the trained maintenance workforce to call on to repair them. One respondent said that he had to get rid of his heat pump, because he did not have the knowledge to fix it, or find someone who could, only to later find out that all that it had needed was a washer that was commonly available to fridge repair maintenance workers! One result of this type of response would presumably be that the original NHER ratings no longer applied, illustrating the need for regulation to focus primarily on the performance of buildings rather than allowing designers to achieve high energy ratings by specifying add-on energy saving gadgets. While there is a place for energy efficient devices, in general, they only make sense if the basic house design is energy efficient. If this involves 'passive' features, and if that is done right, then there is less to go wrong.

If these design and operational problems have emerged in relatively well funded demonstration projects, we can expect them to be just as bad if not worse in less well supported experiments. One of the boldest experiments in low energy house design is the Hockerton earth sheltered passive solar terrace in Nottinghamshire, which houses a community of enthusiasts for environmentally sound living. Although this pioneering project is admirable in many respects, the constraints on funding seem to have meant that each house unit is narrow and of identical shape, as defined by the length of the standard roof beam that was chosen (15). The result is a rather uniform aspect to the housing, perhaps reasonable for hostel type accommodation, but arguably rather constraining for family residences (16).

This brings me to the second key problem Tam Dougan identified from her Milton Keynes study, relating to the social implications of house design. While some of her respondents commented on the joy of having natural lighting from passive solar designs, and most saw 'light and space' generally as major design benefits, many of the houses were orientated so that little use could be made of sunlight in gardens and patios. Once again, one of reasons was the small plots used for the exhibitions, but small gardens with houses crammed in to obtain maximum density, now seems to have become the norm in modern estates. It may be what busy executives want, but, for many others, having access to well proportioned sunlit garden/patio spaces is a vital part of life and community.

Access to sunlight is also obviously important for solar energy collection. One of the reasons why the solar potential of cities is so good in the UK is the Victorian tradition of terrace layout with reasonable gardens. Modern housing layouts, with small plots, may make it hard to add solar PV on at later stage, when it becomes more economically attractive. The iesson seems to be that urban pianning must piay a significant part. South facing roof aspects with good suniight access shouid be mandated wherever possible in future plans.

Conclusions

I have identified a few practical problems with current attempts at sustainable house design. Some of them relate to basic design flaws and some to wider planning concerns. The main message is that just adding renewable energy systems will not compensate for poorly designed buildings, weak regulations and short sighted planning.

However, I would not want to suggest that there aren't some excellent, well thought out, urban projects around. For example, the Peabody Trust, the RENUE group, and many others, including the national network of d-i-y Solar Clubs, have developed are or developing some very innovative city-based renewable projects.

What is interesting about these projects is the often very high level of local community involvement, especially when compared with the private sector led demonstration housing projects discussed earlier. If we are to move ahead to sustainable cities based on novel energy technologies, then we must expect to have to deal with a lot more design and implementation problems. To try to improve our rate of learning, it seems important to involve users and consumers in the design loop more effectively.

Over the years, various design participation schemes have been devised with varying degrees of success, ranging from more or less total involvement in self-build schemes, to token participation exercises on superficial aspects. As I have suggested, as far as novel urban energy project are concerned, the best schemes seem to be those with strong community involvement, and clearly this is not just a matter of involvement in the technical aspects.

Sustainability is about more that just environmentally sound technology, it is about involving people in the development of environmentally sound life styles. Clearly, that goes well beyond just energy use in buildings, and includes questions concerning transport, shopping patterns and many other aspects of life in cites- all of which have energy implications.

The Local Agenda 21 process is one current focus for local level discussion and debate over how sustainability in all its aspects might be achieved in cities and elsewhere, and there have been some interesting developments in the energy field (17). In particular, Local Councils have been helping local community groups to develop plans for their areas and many have involved proposals for renewable energy projects in urban areas (18).

Unfortunately, with Local Councils being short of funding, most of these projects are however small and starved of funding. Although local projects can inspire and build commitment, a lot more will need to be done if we are to put flesh on the sustainable city vision, not least by central government. It is tragic, for example, that while Germany has a 100,000 PV roof programme and the USA has a 1 million solar roof target, the UK only has a 100 solar PV programme, with PV still being seen at best as a longer term option.

It is true that PV solar is still in its infancy, at least in the UK, but this option, along with the other renewable energy options I have mentioned, offers a chance to deal with the urban energy problem at source. Rather than expecting rural areas to accommodate more and more windfarms, landfill gas sites and so on, so as to supply the cites, the cities can help to meet some of their own energy needs. Certainly, if properly designed, many urban buildings can provide much of there own power (19). However, what is needed to make this a reality is not just technology, it also requires a fundamental revision of design concepts, building practices and planning perceptions. See Box 2 for a checklist of some possible starting points.

Finally, although I have focused on the issue of the energy needs of cities in the UK, clearly this is a world-wide issue. Around 50% of the world's population live in cities and the problem of environmentally hazardous emissions is growing (20). Perhaps, historically, it falls to the great cities created in the West to pioneer the sustainable solution?

Box 2 Sustainable Urban Energy Check List **Derek Taylor**

A preliminary check list of some of the actions needed to support sustainable use in cities.

1. Appropriate Technologies and facilitation strategies to permit urban ambient, hydraulic and biological energy flows to be usefully tapped, particularly at neighbourhood level.
2. Design of buildings to take advantage of ambient energy sources interacting with them.
3. Design of buildings to ultra energy efficient standards. More feasible with urban built forms.
4. Planning of buildings, street layouts etc for renewable energy access.
5. Practice much greater demand side management of energy use in homes and local industry.
6. Effective encouragement of passive measures to optimise solar gains for heat, cooling, day lighting and ventilation measures.
7. Effective landscaping measures for moderating local climate around buildings and in streets.
8. Effective landscaping measures for planting, management, harvesting and local utilisation of energy crops and landscape trimmings.
9. Greening brown field sites with energy crop landscaping.
10. Rather than utilising all brown field sites for new building, opening such sites for renewable energy should be given serious consideration.
11. Extending solar access has to be part of planning neighbourhoods for future sustainability.
12. Utilising roofs as solar and wind energy harvesting devices.
13. Utilising green roofs for better utilisation of land in cities and elevated landscapes.
14. Atriumising courtyards, spaces between buildings & streets can provide passive solar energy for heating and cooling – if properly designed and <u>not</u> air conditioned or heated.
15. Optimising sewage processing for local energy production, and utilise nutrients to grow urban energy crops.
16. Local urban renewable / sustainable energy companies may provide appropriate mechanisms for utilising urban renewable energy effectively provided enough energy consumers are prepared to contract to purchase their energy through such a local company.

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(13) 'Sustainable Housing: some lessons from Milton Keynes', Tam Dougan NATTA report, 1998.

(14) See Tam Dougan's review of the Integer project in Building for A Future Vol. 9, No. 1, 1999, pp 13-22

(15) See Tam Dougan's comments on the Hockerton project in Renew 123, Jan/Feb, 2000, p13.

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(17) See for example the 'Leicester Energy Strategy' Local Agenda 21 report, Leicester City Council, 1995. This proposes a target of a 50% reduction in energy use, on 1990 levels, by 2025.

(18) See the NATTA /AMBIT video 'Green Energy: Local Agenda 21 in Action', NATTA, Milton Keynes, 1998.

(19) For further discussion see 'Renewable Energy for Housing' Derek Taylor in Edwards, B and Turrent, D. (eds) 'Sustainable Housing' E.F.Spon, 1999.

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Dr David Elliott is Director of EERU, the OU Energy and Environment Research Unit. Dr Derek Taylor is a member of EERU and a principal in the Altechnica consultancy.

Building for Sustainable Development
"Sustainability – a Practitioner's View Point"

Iain A Paul, Dip Arch RIBA
Worcestershire County Council Design and Estates Unit

Introduction

Today's programme amply demonstrates how the principles of sustainable development can have a major impact upon the thinking of Engineers, Architects and Quantity Surveyors towards materials, technology and design. The following presentation outlines the impact of sustainability upon a public authority's approach to building design and performance.

Background

Worcestershire County Council is a local authority responsible for the stewardship of a public estate worth £400 million. The Council committed itself publicly to the principles of Local Agenda 21 in 1996. It elected, through its Environmental Action Plan, to apply the principles of sustainability to the management of its estate and where possible to use capital projects as expression of environmental best practice. Responsibility for this approach rests largely with the in house Design Consultancy. The Consultancy is multi-disciplinary and also draws upon the support and knowledge of a separate Energy Management team who monitor the performance of over 200 buildings of varied age, type and condition. The performance data informs and influences the Consultancy's design work.

Local Agenda 21 is a key driver and the Environmental Action Plan is a major tool in developing policy and approach. (In the public service at least, the political dimension to sustainability cannot be ignored.) The approach, which now encompasses everything from the management of smallholdings to the procurement of consultancy services (50% of all work is undertaken by consultants), is evolving continuously.

Four particular projects spanning the last six years illustrate the process of evolution, the opportunities and the pitfalls. The first project is an environmental education centre followed by a public library and two school developments.

Bishops Wood Environmental Education Centre

Bishops Wood Environmental Education Centre was the Consultancy's first experience of engaging a client in serious environmental debate. The sponsoring client was National Grid plc, anxious to display its environmental credentials but determined to avoid gimmick labels. The ensuing debate highlighted the general lack of environmental knowledge at the time and the risks clients feel in being associated with innovation. It also re-emphasised the critical nature of design team working.

The building which was completed in 1994 was conceived as a three dimensional text book, incorporated a range of materials and features which have since become accepted parts of the design and construction repertoire. The entire design process including the selection of all materials and methods was subject to considerable scrutiny by the centre's environmental education staff. The design is based on timber frame construction on minimal concrete foundations. High thermal performance and a healthy physical environment were achieved by adopting breathing wall technology. For the first time, the design team considered the environmental impact of materials selection in its widest sense. This led to the specification of, wherever possible recycled materials, organic paints and surface treatments, ethical selection of timbers and minimal use of products with high embodied energy.

At the specific request of environmental educationalists, the designers incorporated water recycling and reed bed water treatment in the scheme. The latter set an interesting precedent and four further reed beds have been constructed on small holdings. The technology is simple, the capital cost low, environmental impact positive and most critically, the cost savings from reduced water charges to tenants is substantial.

Project development coincided with the publication of the first draft of BSRIA's Environmental Code of Practice for Buildings and their Services. The Code has been the framework for the development of subsequent projects and marked the beginning of a fruitful on-going relationship with BSRIA.

Kidderminster Library

The site for Kidderminster Library is the antithesis of Bishops Wood. With a narrow strip of derelict land on one side and a seventies multi storey car park and redundant carpet factory for neighbours it was an uncomfortable introduction to design for sustainability in an urban context. Three floors of accommodation are connected by a glazed atrium - the main circulation zone and social space. By exploiting the stack effect, a high level of natural ventilation was achieved. In spite of extensive dialogue with the building users, the approach was viewed initially with considerable scepticism. It came as a great surprise to staff to discover they were comfortable in their new building without our air conditioning. Savings in CO_2 emissions are estimated at 32 tonnes per annum with no increase in initial capital cost.

Less successful, in this case, were the design teams efforts to apply greater environmental responsibility to materials selection. Facing bricks were manufactured ten miles from the site and linoleum once again replaced vinyl flooring alternatives. The Council had by this time formally adopted a policy of reducing its use of PVC products in construction. The town planners were, however, insistent that the aluminium roof although barely visible except from the adjoining car park be colour coated. The fact that the extra coating process is highly polluting did not figure in their thinking.

Weobley Primary School

Weobley Primary School is the first wood fuelled school in the country. The project was intended to demonstrate the viability of small-scale biomass heating in the public sector. It was also adopted as a case study to test the final version of the BSRIA Code of Practice.

The wood fuel boiler and associated infrastructure were funded by a partnership of ETSU, MAFF 5B, the Rural Development Commission and the County Council. The system is in its second year of operation and currently achieving a 65 tonnes per annum reduction in CO_2 emissions. Although there have been numerous teething problems there is confidence in the concept and work is underway on a network of further projects. The network is intended to achieve the dual benefit of assisting with the further reduction in CO_2 emissions and contributing to the ailing rural economy.

Extra funding for biomass at Weobley did not translate into higher budgets for the building itself. A key objective for the design team was to establish how far the environmental agenda could be advanced within DfEE cost guidelines. The outcome can best be judged by a visit to the building itself but some key points do emerge from any analysis.

The orientation and sectional arrangement of the linear plan form maximised daylight and cross ventilation without incurring any cost penalties. The team's proposals for a timber structural frame were abandoned on cost grounds in favour of cross wall construction. As with a number of current school projects, the question of future flexibility of use remained unanswered. Although the approach to construction methods and materials was heavily constrained by the budget the design team pursued their sustainable approach vigorously.

The breathing wall with Warmcell insulation once again proved to be a very cost-effective way of achieving high thermal performance. This time it was also used as a roof insulation. Subsequent thermal imaging of the building in operation confirmed that the selection of this technique and the associated detailing to maximise air tightness has produced a building envelope which is very thermally efficient.

Forest Stewardship Certified (FSC) timber for roof construction and general carcassing had to be omitted from the specification because of cost. The explicit use of structural timber (albeit from a non-certified source) with its message of low embodied energy was nevertheless adopted. This was partially funded by the structural engineers very economic use of concrete. Minimising the volume of concrete and opting for low cement content were two of the engineers responses to the environmental agenda. The use of recycled aggregates was rejected because of concerns about cost, quality, consistency and design liability.

A small but important decision was the selection of safety flooring made from natural rubber, more expensive than the conventional alternatives but known to be from a renewable resource. Finding acceptable and affordable alternatives to conventional highly polluting plastics based finishes and components is a constant difficulty.

Selecting an acceptable roof finish was difficult. Finally clay tiles were adopted. Although higher in embodied energy than the concrete equivalent, they were deemed most appropriate because they can, in the long term, be more effectively reused. Perversely, the town planners objected to the choice because it did not match the adjoining houses which are concrete tiled.

The design teams concluded that it is possible to specify materials and assemblies with low environmental impact within normal cost guidelines. They were, however, particularly concerned about the building's lack of long term flexibility and also the lack of significant water conservation and rainwater recycling measures.

Rubery Primary School and High School

Responding to the environmental agenda continues to influence the Council's approach to construction and estate management. This is exemplified by a development upon which site work has just begun. The project is the largest part of a district wide initiative to improve the quality of teaching facilities by partial removal of surplus spaces and rationalisation of accommodation. The proposal involves major extensions to a high school and a primary school on a shared site at Rubery on the edge of Birmingham. Consultants Architype were appointed for the high school. For the first time a quality based appointment selection process was adopted. The consultant's environmental statement was a key factor in the final selection. The in-house team, to which the same criteria applied, is undertaking the primary school project. The design teams share common goals and there has been significant exchange of information and experience.

In both cases the final design solution was to wrap the existing accommodation with the new building. This approach optimised the wall to floor ratio of the overall development and enhanced the thermal performance of the existing buildings. The project teams responses to DfEE Bulletin 87 Guidelines for Environmental Design in Schools differed, particularly in relation to ventilation requirements. The High School team took the view that only a fully engineered approach would achieve both the required thermal performance and the 8litres per second ventilation rate. This led to the adoption of the Termodeck system to provide both heating and cooling. Fortunately the higher cost allowance for the High School was sufficient to cope with the increased capital cost involved. The primary school's budget limitations required a more pragmatic approach. This involved maximising the opportunities for conventional cross ventilation and the adoption of underfloor heating linked to a condensing boiler.

High levels of daylight and thermal insulation have been achieved in both schemes. It is intended that the schools will monitor and compare the performance of the new developments. They will be aided by the Council's Energy Management team and Environmental Education staff. The data collected will be a valuable reference for future projects. More importantly, it is hoped that teaching staff and children will assume ownership of the design concepts and be encouraged to use their schools in an environmentally responsible manner.

A site wide water management strategy has been devised to resolve persistent flooding problems. A system of swales and balancing ponds has been designed to manage rainwater run off. The scheme, which also incorporates a degree of rainwater recycling, will result in a substantial reduction in water charges for both schools with consequent long term effects on premises related costs.

The final component of the development serves as a reminder to the engineers and architects of the behavioural aspect of environmental impact. The majority of pupils are within walking distance of the two schools yet every morning the roads are choked with cars delivering children direct to the school door. Both schools are working with Education and Transportation staff on a Safe Routes Initiative aimed at a dramatic reduction in vehicle movements to and from the site. The Initiative will involve the improvement of public transport arrangements, the creation of physically secure pedestrian routes for the children and the introduction of the novel concept of the 'walking bus'. If successful, this may well have an even greater, long term environmental impact than the measures currently being adopted by the designers for the new accommodation.

Conclusion

In conclusion, whilst the author does not subscribe to the concept of an explicit architecture of sustainability, the projects discussed do illustrate some common themes which can be summarised as follows:

- User involvement in the design and subsequent operation of the buildings.
- A site specific response to climate.
- An awareness of the wider environmental impact of materials and assemblies specification.

Bishops Wood Environmental Education Centre

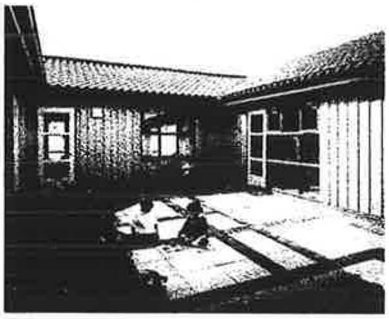
Architects:	I A Paul	)
	D J Millis	) Worcestershire
	D Bicknell	) County Council
M+E Engineers:	R Russell	)
	R H Colley	)
Quantity Surveyor:	T L Hackling	)
Structural Engineer:	TRADA	

Kidderminster Library

Architects:	D J Millis	)
	D Bicknell	) Worcestershire
M+E Engineers:	R Russell	) County Council
	R H Colley	)
Quantity Surveyor:	T L Hackling	)
Structural Engineer:	Building Design Partnership	

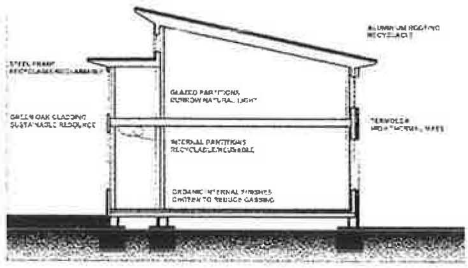
Weobley Primary School

Architects:	D Galvin	)
	I A Paul	) Worcestershire
M+E Engineers:	C Saxon	) County Council
	J Moss	)
Quantity Surveyor:	T L Hackling	)
Structural Engineer:	Building Design Partnership	



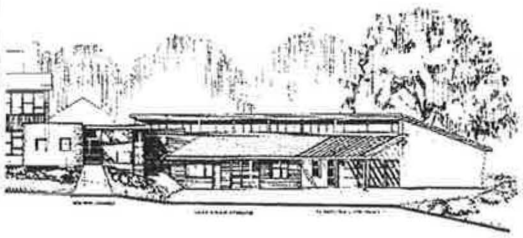
Rubery High School

Architects:	J Hines	) Architype
	S Brown	)
M+E Engineers:	Fulcrum	
Quantity Surveyor:	Bridgewater & Coulton	
Structural Engineer:	Shire Associates	



Rubery Primary School

Architects:	D Bicknell	)
	K Worboys	) Worcestershire
M+E Engineers:	R Johnson	) County Council
	N Papadopoulos	)
Quantity Surveyor:	T L Hackling	)
Land Surveyor:	M Harris	)
Structural Engineer:	Shire Associates	



Urban Agriculture and the Sustainable City

Andre Viljoen and Katrin Bohn
Low Energy Architecture Research Unit
School of Architecture and Interior Design
University of North London
6-40 Holloway Road,
London N7 8JL
United Kingdom

ABSTRACT

It has been estimated that modern remote food production is responsible for greater carbon dioxide emissions per household than the energy used in a home and the energy used for a private car. This paper discusses how ecological and architectural ideas may generate proposals for sustainable cities that integrate Urban Agriculture thereby reducing the cities' environmental impact. The concept of "Ecological Intensification" is introduced. A series of case studies examines the potential yields from Urban Agriculture for a range of densities and occupation patterns.

INTRODUCTION

Geographers and Ecologists have developed a more coherent methodology for describing the interaction of humans with the wider environment than have architects or building physicists. An understanding of these interactions may help designers to place their work in a wider environmental context and, furthermore, to conceptualise design strategies.

The description of an ecosystem provides a useful model for understanding the relationship between humans and nature: The ecology of an area can be considered as the relationships of a set of organisms to each other and to their specific surrounding. Ecology stresses interaction between all parts of an area. We can designate areas of specific ecological components and call them ecosystems (I.G. Simmons 1981).

An ecological concept, familiar to those dealing with the built environment, is that of resource process. Resource process allows us to understand the interdependence of different organisms within an ecosystem. It traces the flow of materials or energy from a primary state in nature through their use by humans to final disposal (I.G. Simmons 1981).

In order to map the energy and material flows through an ecosystem, a set of trophic levels is defined. Typically, the first level is the sun, followed by species of plants, herbivores and carnivores. If the number of plants or individuals is measured in each trophic level, it can be seen that higher trophic levels contain relatively low populations and depend upon larger lower levels.

Table 1 represents the conditions within natural ecosystems primarily reliant on the input of solar radiation. Within these natural systems, the population of a given trophic level is dependant upon the inputs from lower trophic levels. This dependance can be altered, if additional energy is fed into the lower trophic levels.

Trophic Level	Ecosystem			
	Summer: Grass land. Numbers per 0.1 ha.	Summer: Temperate forest. Numbers per 0.1 ha.	Silver Springs Florida: Standing crop biomass. kcal/m²/yr	Silver Springs Florida: Energy flow through tropic level kcal/m²/yr
Top Carnivore	1	2	1.5	21
Carnivore	90 000	120 000	11	383
Herbivore	200 000	150 000	37	3368
Plants / Primary Producers	1 500 000	200 (Large trees, few in number)	809	20810
Table 1	Source (I.G. Simmons 1981 - E.P. Odum 1971)			

Food production and energy input

Current agriculture and food production illustrate how additional energy inputs can be used to modify the output of an ecosystem. Typically, the additional energy is derived from non-renewable sources and used for the production and application of fertilisers, insecticides, pumped irrigation, transportation, packaging and preservation of crops.

If this amount of "low level" energy and the related CO_2 emissions are taken into account, current food production in developed countries is seen to be highly inefficient.

As an example, Figure 1 illustrates the energy subsidies to the food system in the U.S.A. between 1910 and 1970. It can be seen that from circa 1920 the amount of additional

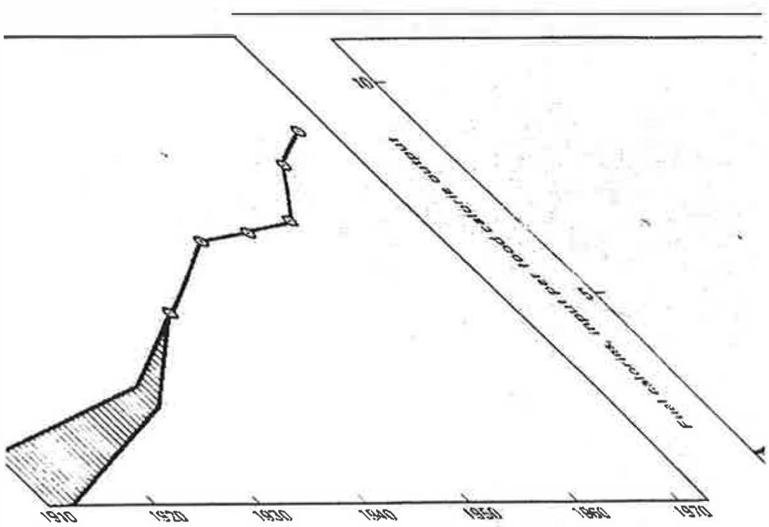


Figure 1: Energy subsidies to the food system from farm to consumer in the USA: The number of calories put into the system to obtain one calorie of food. Values for 1910-1937 cannot be fully documented so a range of probable values is given. Source : I.G. Simmons, 1981 / Steinhart & Steinhart, 1974

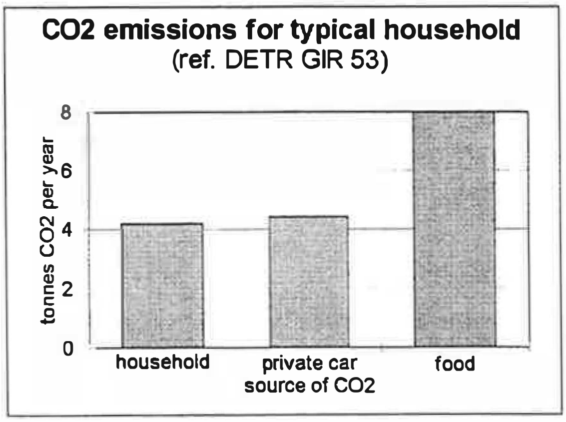


Figure 2: Comparative carbon dioxide emissions for a typical U.K. household Source: B. Vale, R. Vale, 1998

energy put into the agricultural system became greater than the inherent energy content of the food itself. By 1970, for every calorie of food consumed, approximately 8.5 calories of energy had been used to produce that food.

Figure 2 presents recent comparative estimates for CO_2 emissions resulting from modern remote food production and from energy used in the home and for a private car (B. Vale, R. Vale, 1998). The figures are based on estimates for a family of four. They suggest that CO_2 emissions due to remote food production would equal the sum of emissions resulting from a home and a private car. (An allowance for inaccuracy should be made as the CO_2 emissions calculated for food are based on agricultural and food production figures published in 1975.)

The potential scope for reducing CO_2 emissions for food production lies in two principal areas: 1) in the use of highly mechanised, fertilizer and insecticide dependant agriculture and 2) in remote food production resulting in significant transportation between farm and consumer. The ideal means of reducing the environmental impact of food production would be to develop local organic means of production. This suggests the development of Urban Agriculture.
We understand Urban Agriculture as the integration of commercially viable agricultural areas in the form of mini & SUPER Market Gardens into wider green or open spaces within the city scape.

URBAN AGRICULTURE AND THE SUSTAINABLE CITY

Urban Agriculture and Sustainability

As Table 1 indicates, large numbers and varieties of plants and animals are found in natural ecosystems. Once the notion of a crop for human consumption is introduced, certain species become considered weeds or pests. Current mechanized farming attempts to increase yield by eliminating weeds and pests, one result are mono-cultures. As Simmons points out, pests and weeds are a cultural notion, eliminating them entirely reduces the bio-diversity inherent in natural ecosystems. Clearly, significant numbers of people would be put at risk of famine if pests were not controlled, but alternative organic high yield methods of farming are being developed. While these alternatives remain on the fringe, their benefits with respect to bio-diversity are clear. For example "Permaculture" (B. Mollinsion 1988), which can form part of Urban Agriculture, advocates the intensive use of land with mixed crops, sometimes mutually supporting each other.

Organic agriculture does not necessarily imply local production. But in energy terms, the greatest benefits from Urban Agriculture will result from reduced transportation requirements for food supply.
There are also wider environmental and social benefits which can result from the introduction of Urban Agriculture. For example, in addition to reducing CO_2 emissions, Urban Agriculture would result in ecological corridors and green islands within cities and promote the local recycling of organic waste for use as compost. Socially, the market gardens would provide new employment opportunities and an educational amenity.

Urban Agriculture and Development

Urban Agriculture can be integrated into new urban developments and the redevelopment of brownfield sites within existing cities. An examination of the land requirements of different agricultural sectors indicates that fruit and vegetable production is most appropriate for urban situations. Grain and cattle require areas incompatible with urban densities. Within Europe, a plot of approximately 100 m² will supply all of the annual fruit and vegetable requirements of an individual (A.Viljoen, A.Tardiveau, 1998).

By Urban Agriculture we do not envisage the creation of allotments in the city. It is not plausible to imagine every household being responsible for growing their own food. It is however possible to imagine the development of urban market gardens of sufficient size to be economically viable as a business proposition for one or two persons. Depending upon their size, the authors call these urban interventions "mini and SUPER Market Gardens". The concept is that indigenous crops produced by those mini and SUPER Market Gardens are sold locally, for example in supporting supermarkets.

Ecological Intensification

Any new development in a city has to be assessed against the increased environmental load it will generate. The process of reducing a development's negative environmental impact through the utilization of natural on site renewable energy systems is one we call "Ecological Intensification"
Urban Agriculture applies principles of Ecological Intensification by its intensified land use, encouraging bio-diversity and an increased site yield.

Ecological Intensification can be measured in terms of site yield and the area's ecological footprint.
Site yield is a measure of the percentage of any utilized resource which is renewable and supplied from within the given site. For example, a household being supplied by the local market gardens with all of its vegetable requirements would have a site yield of 100% for vegetable consumption.
The concept of ecological footprints, developed by Wackernagel (M.Wackernagel, W.Rees, 1996), allows for the estimation of the land area required for the sustainable support of any development. Ideally, any development would have an ecological footprint equal to its site area.

Urban Agriculture and Landscape

We would contend that Urban Agriculture has a beneficial psychological impact for urban

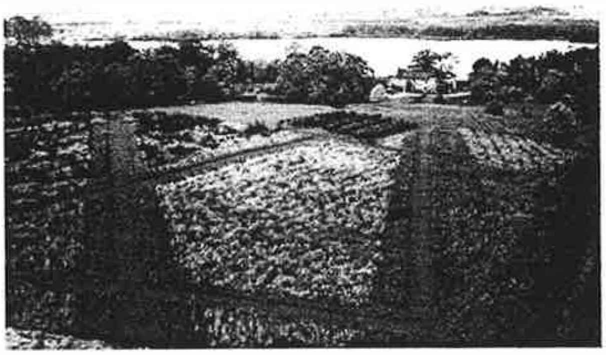


Figure 3: New landscape elements: Clues from patchy market gardens in Norfolk.

dwellers and may help to reduce the drift of populations out of the city and into rural/suburban areas. It is clear, that most urban populations who move into the countryside, do not physically engage with the land, but rather with an idea of "the countryside" or "of nature". Market gardens can introduce a notional piece of the countryside into the city, thereby making city centres more attractive for people.

Urban Agriculture makes seasonal changes visible and provides a new landscape type. It makes life and our relationship to the wider environment more comprehensible. Next to the visual enrichment, it has a pedagogic value, marking an element of sustainable development.
As a landscape element, Urban Agriculture has affinities with contemporary urban theory, discussing patchy landscapes and infrastructural urbanism, as proposed by Allen (S. Allen, 1997).

CASE STUDIES

Five case studies for housing projects of different density are presented in this paper: Southwark, London (density 72 persons/hectare), Sheffield (density 92 persons/hectare), Newark (density 214 persons/hectare), Shoreditch Horizontal, London (density 300 persons/hectare) and Shoreditch Vertical, London (density 450 persons/hectare).
Typical densities for current housing in the U.K. are 20-30 dwellings per hectare or approximately 100 persons per hectare (Rogers *et al., 1999)*.

Each case study was designed from the outset to accommodate Urban Agriculture. A range of densities have been considered to test the impact of density on site yield. The authors accept the desirability of developing the "compact and well connected city" in order to reduce transportation requirements. However, we contend that density should not be used as the sole measure of assessing the potential sustainability of an urban development.

Site Yield

All case studies have had their Urban Agriculture yield assessed. At the time of writing, three of the case studies have also had site yields tested for electricity generation from photovoltaics, solar hot water contribution to domestic hot water requirements and potential rainwater harvesting for domestic use.
Criteria set out in the General Information Report "GIR 53" (B.Vale, R.Vale, 1998) have been used to assess energy and water demands for each case study. These are based on buildings built to "super insulation standards".
Solar hot water systems assume an overall efficiency of 50%, and grid connected p.v. systems have an assumed efficiency of 15%. The yield from market gardens is based on a requirement of 100 m² per person for the supply of all fruit and vegetables in a year. Rain water harvesting capacity is based on the roof area of buildings and site location.

Density

Approximately 30 m² of accommodation per person has been used when calculating site density (number of persons per hectare), although this measure varies with specific designs.
The site boundary becomes an important parameter when calculating density as this determines site area. Within this study, the boundary is drawn around the edge of the

housing and live/work areas. The site area used to calculate site density includes all market garden areas and circulation spaces, but excludes other public open space such as parks and playing fields except where these are located on roofs of buildings.

Case Study: Southwark, London
Density 72 persons per hectare,
Annual Urban Agriculture yield: 70% of fruit and vegetable requirements

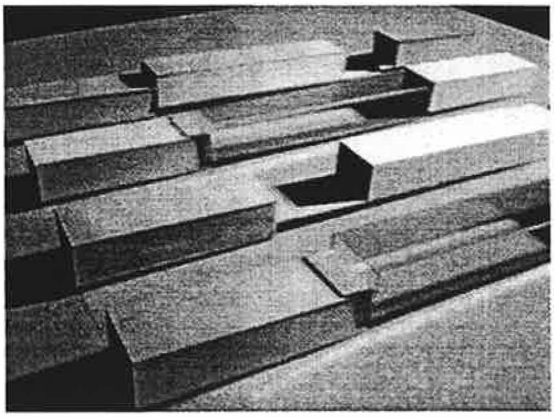
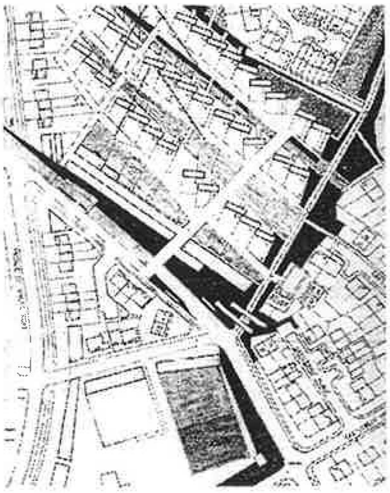


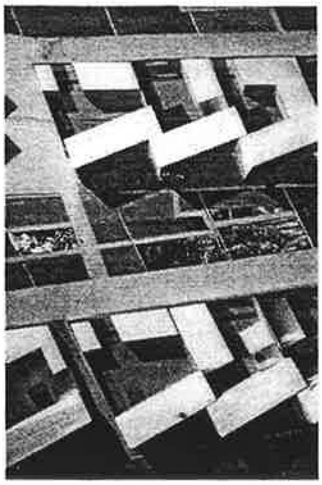
Figure 4: Southwark, London: Site model showing the arrangement of single storey linear dwellings. Green houses separate individual dwellings, and mini Market Gardens are located between the dwelling terraces.

This scheme is located in an area of social housing. It is low cost housing itself which can be constructed simply.
The site is an abandoned piece of land south of a multi storey apartment building. The horizontal site strategy responds formally to the adjacent vertical apartment building.

The proposal introduces an innovative live/work idea:
Market gardens are positioned between thin terraces containing dwellings, patios and greenhouses. They can provide 70% of its residents' annual fruit and vegetable requirements.
The greenhouses separate individual dwellings, supplying plants for the market gardens and contrast with the materiality of the dwellings. Dwellings do not have gardens, but are abutted by the market gardens. Patios within the dwelling strip provide private external space for residents.
Housing terraces face south, and heliodon studies were used to optimize spacing for passive solar gain. Roof tops can also easily support active solar systems.

Case Study: Sheffield
Density 92 persons per hectare,
Annual Urban Agriculture yield: 30% of fruit and vegetable requirements.





Figures 5 & 6: Sheffield: Site plan and model, illustrating how market gardens form part of a wider landscape strategy, creating a "Continuous Landscape". The model shows individual two storey dwellings with south facing plots. These plots can be used as individual gardens or accommodate an extension to living/working accommodation.

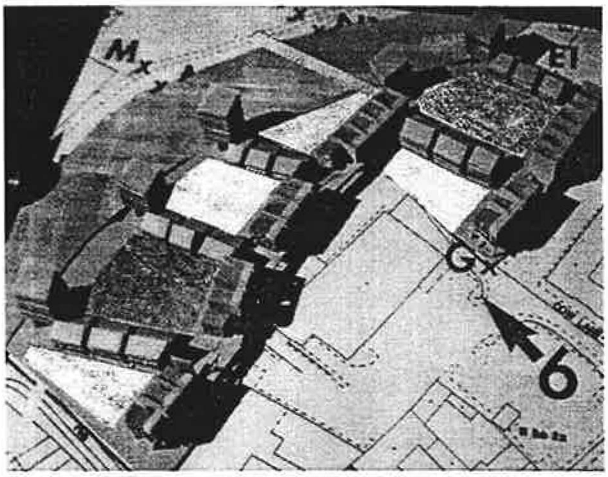
The site plan for the Manor Estate in Sheffield shows how Urban Agriculture can be integrated into an architectural and landscape strategy. The proposal develops the idea of Continuous Landscape and Proximate Agriculture. Continuous Landscape is a proposition for connecting existing parcels of open land, which form ecological corridors and a landscape amenity. Proximate Agriculture refers to the integration of mini- & SUPER Market Gardens into the Continuous Landscape for food, work and pleasure. These market gardens produce indigenous crops commercially and for local consumption.

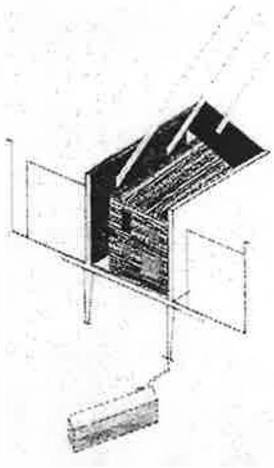
Market gardens form landscape fingers running between housing plots which are located in relation to topography and solar access. Each housing plot contains a spine dwelling which provides accommodation for a small family group. A plot to the South can be used as a garden, car parking space or for an expansion of working/living accommodation.

Case Study: Newark
Density 214 persons per hectare,
Annual Urban Agriculture yield: 15% of fruit and vegetable requirements

This site is situated alongside the River Trent and accommodates two types of terraced dwellings and 5 three to four storey high apartment blocks.
The two storey terraces bounding the site to the East are built on columns with circulation and parking below and private roof terraces above. With this vertical layering of activities Ecological Intensification is achieved: The site density increases, freeing other land for agricultural use.

Individual dwellings in the raised terraces have an east-west orientation. Difficulties associated with east-west oriented solar dwellings are avoided by creating a top lit circulation slot. This slot can accept solar gain during the heating season, indirectly heating





Figures 7 & 8: Newark: Site model showing arrangement of Urban Agriculture fields surrounded by dwellings. The drawing to the right illustrates how dwellings with an east-west orientation accept direct solar again. The roofs of all dwellings support s.h.w. panels and collect rainwater.

habitable rooms which are wrapped in insulation. Shutters control glare and heat loss. Roof mounted solar hot water panels provide all d.h.w. requirements. Roof tops collect rainwater which is channelled into underground storage tanks and provide private patios.

Market gardens are placed between the north-south oriented terraces, which slope down from the raised terraces to the river bank. By sloping this terrace self shading of the site is reduced and landscape can run continuously under the dwellings.

Case Study: Shoreditch Horizontal, London
Density 300 persons per hectare,
Annual Urban Agriculture yield: 15% of fruit and vegetable requirements.

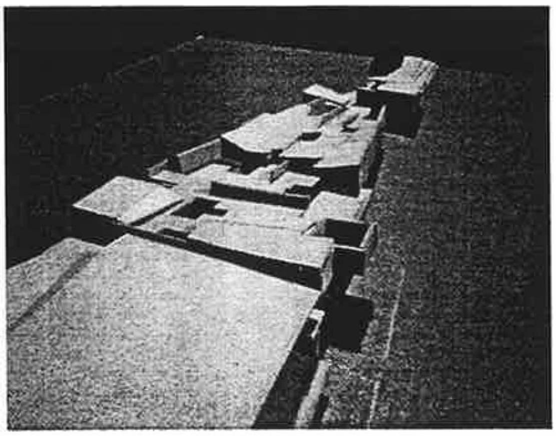


Figure 9: Shoreditch Horizontal, London: Site model looking towards housing with roof top market gardens.

The site reuses abandoned railway viaducts, east of the City in London. Two storey courtyard housing is placed above the viaducts. This dense housing is connected to working spaces located within brick vaults that form the viaduct. Courtyards are proposed which bring daylight into the vaults and provide at upper levels semi private gardens. The roofs of the dwellings form undulating fields accommodating mini Market Gardens.

Case Study: Shoreditch Vertical, London

Density 450 persons per hectare:

Annual Urban Agriculture yield 11% to 33% of fruit and vegetable requirements.

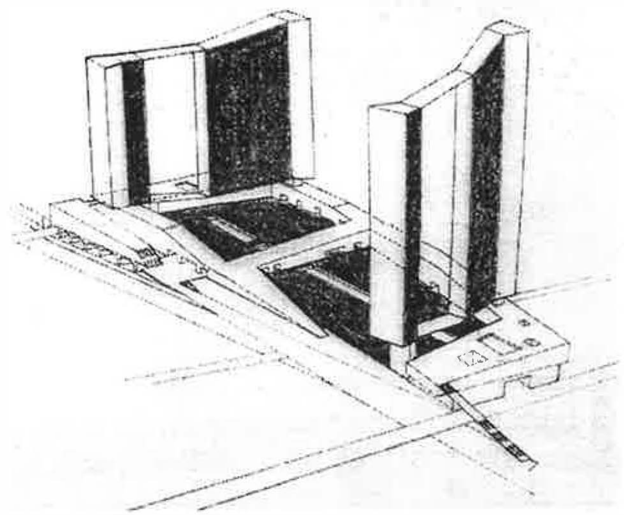


Figure 10: Drawing showing the form of the urban nature towers and surrounding perimeter housing. Shading indicates the horizontal and vertical market gardens.

Shoreditch Vertical proposes two Urban Nature Towers surrounded by low rise accommodation framing two urban fields. Two multi functional “Urban Nature Towers” accommodate apartments and public facilities. They are oriented so as to maximize solar access to the fields, and minimize overshading of surrounding sites. The thin section of the Towers allows for daylighting and passive environmental conditioning.

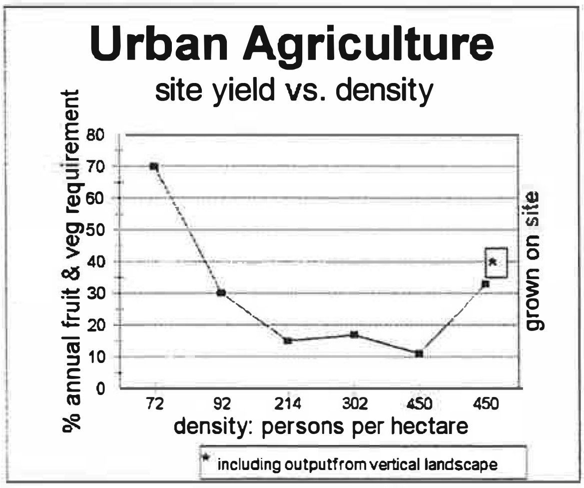
The roofs of perimeter low rise dwellings become a public park creating a continuos landscape within the city. On the horizontal plane, market gardens provide a visual focus for the site. With an area of 10 000m² they will yield sufficient fruit and vegetables for 100 people. This equals 11% of the two hectare site’s 900 inhabitants requirements.

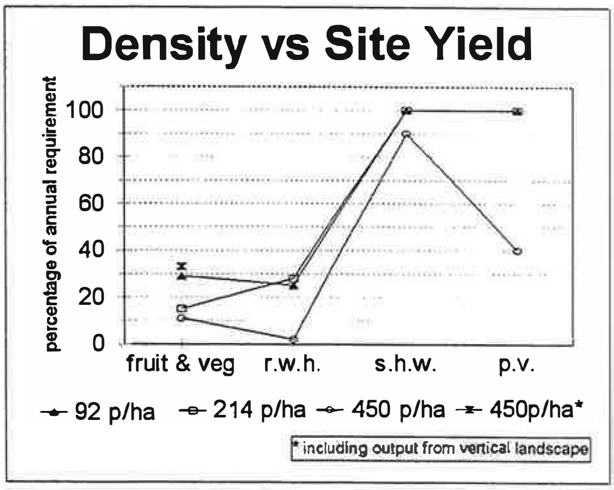
On the vertical plane of the Urban Nature Towers, fruit and vegetables are cultivated on a steel frame by employing a system of planting troughs. They are irrigated with grey water collected from the towers. This skin of espaliered food production acts as a screen through which private balconies project. It is estimated that the vertical fields will yield enough fruit and vegetables to feed 200 persons, an additional yield of 22%.

Even in a dense urban context, this "urban farm" is able to produce 33% of the two hectare site's fruit and vegetables requirements.

DISCUSSION OF RESULTS

Figure 11 compares the yield from Urban Agriculture for the five case studies. Yield is related to density.





Figures 11 & 12: Assessments of Ecological Intensification using site yield as a measure.

Figure 11 shows that Urban Agriculture can be expected to provide between 10% and 70% of a sites annual fruit and vegetable requirements. While Urban Agriculture should not be expected to provide autonomy for fruit and vegetable requirements in cities, it could make a significant contribution to reducing a city's ecological footprint. This, in association with wider sustainability benefits identified earlier, suggest it is a viable option for future urban proposals.

Figure 12 provides a broader assessment of Ecological Intensification and plots density against site yield for fruit and vegetable production (fruit & veg), rain water harvesting (r.w.h.), solar hot water for domestic hot water (s.h.w.) and electricity generation for domestic use using photovoltaics (p.v.).
Results are presented for three of the case studies, Sheffield, Newark and Shoreditch Vertical. It appears, that density has a relatively small impact on the potential for solar hot water generation. Site generated electricity can potentially meet 100% of domestic electrical requirements for energy efficient homes up to densities of approximately 200 persons per hectare.

The impact of transport and embodied energy have not been explicitly considered in this study. The largest site in this study was Shoreditch Vertical at two hectares (450 persons per hectare) and this area can quite plausibly be integrated into a cities sustainable transportation strategy.

Previous investigations into the total environmental impact of low energy dwellings have indicated that when taking account of embodied energy, dwellings designed to meet zero energy criteria have the lowest total environmental impact. (Viljoen, A 1997). This may not be the case for high rise buildings such as those proposed for the Shoreditch Vertical site.

CONCLUSION

The results presented here suggest that Urban Agriculture has potential as a viable strategy for reducing a cities ecological footprint. Taken together with the notion of Ecological Intensification, it provides a framework for visualising the morphology of a sustainable city.

Urban Agriculture can be expected to provide up to 30% of a population's fruit and vegetable requirements at densities of circa 100 persons per hectare. If more intensive methods of Urban Agriculture are developed, for example Vertical Agriculture, then these densities can be increased.

More work is required to assess the size of economically viable mini or SUPER Market Gardens.

ACKNOWLEDGEMENTS
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The case study for Shoreditch Horizontal, is based on a design by Olivia Nangle. Both are architectural students at the University of North London.
All other case studies are designed by the authors.

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Urban Environmental Research
Its role in the practice and policies of sustainable development

Koen Steemers
The Martin Centre for Architectural and Urban Studies
University Of Cambridge Department of Architecture
6 Chaucer Road, Cambridge CB2 2EB, UK
Tel: (44-1223) 331700. Fax: (44-1223) 331701.
Email: kas11@cam.ac.uk. Web: www.arct.cam.ac.uk

Abstract
The topic of sustainable urban development is currently and increasingly widely discussed and written about [1]. This paper discusses three main themes: practice, policy and research. It reviews historical and recent work in these areas, draws on key projects and raises questions regarding the interrelationships. The emphasis of this paper is on the role of analytical research, which should have key role to play in advancing the current state of play. Although there is a significant degree of consensus among many key 'actors', there is greater need for critical interaction and cross-fertilisation between the three sectors - practice, policy and research - if the overall outcome is to be convincing and beneficial.

Introduction

Vernacular precedent

A brief review of vernacular urban form in extreme climates reveals a strong link between environmental forces and design response. For example, the typical characteristics of a hot arid city are as follows: Narrow streets providing mutual shading of the buildings and streets. Internal deep courts, losing heat to the sky at night and containing a pool of cool air for the day. Masonry construction ensuring that the coolth of the night is stored for relief during the hot day. The urban grain of Marrakesh in Morocco demonstrates the typical hot-arid urban response of narrow streets and courts to provide shade [2].

The urban character can become dominated by a specific climatic opportunity to improve environmental conditions. This is exemplified by the wind scoops which dominate the urban grain of Hyderabad, all facing the prevailing cool sea breezes as the land-mass heats up during the day, and turned away from the dust-laden desert winds [2].

Similar examples can be shown for warm-humid urbanism, with its more 'permeable' structure; or Mediterranean climates where towns exploit the cool breezes, as with typical Italian hill towns; or cold climates where low, valley-hugging forms avoid cold winds.

It is clear that urban design has had and should have a significant role to play in moderating extreme climates to create a more amenable environment. In the

European context, where climates are generally more moderate than the above examples, the question arises: What is the influence of urban design on the environment?

1.2 19th and 20th century European environmental urban developments

It is interesting to note that many urban 'theories' over the last 150 years have often given a negative view of contemporary process of urbanisation, forecasting imminent crisis as a result of environmental unsustainability. This is not so different today where the Urban Task Force claims that failure to meet a target of 60% of new dwellings to be built on 'brownfield' (previously developed) land "will lead to fragmentation of the city and erosion of the countryside. It will also increase traffic congestion and air pollution, accelerate the depletion of natural resources, damage biodiversity and increase social deprivation" [3]. Following such forecasts of doom, new theories and proposals are presented, aiming to avoid the 'inevitable' cataclysm, often, ironically enough, with little regard for or clear analytical appraisal of the environmental aspects.

However, urban interventions and ideas were proposed which do respond to and reflect environmental issues. For example, the work of Chadwick [4], who was concerned with the health and welfare of the poor in UK cities, resulted in the Public Health Act of 1875. This act not only prescribed new standards for sanitation, but also for street widths and space around buildings to ensure fresh air and good daylight. This has had significant influence on the urban texture of housing areas, moving away from the tight-knit chaos of back-to-back housing to more rational terraced layouts.

Ebenezer Howard's idea for the Garden City was based on the need to take pressure off the congested city and move people out, to closer proximity with the country. In his Three Magnets the negative environmental conditions of "Foul Air", "Fogs & Droughts" and "Murky Sky" of the city were to be exchanged for the "Fresh Air" and "Bright Sunshine" of the country [5]. But what of the city that is left behind? Those that could not afford to move to these new suburbs were left in the urban slums that were ultimately raised to the ground and replaced by 60's high-rise, with all the ensuing social and physical problems.

Le Corbusier explicitly expressed his concerns of urbanisation as follows:

"The city is crumbling, it cannot last much longer; its time is past. It is too old. The torrent can no longer keep to its bed. It is a kind of cataclysm. It is something utterly abnormal, and the disequilibrium grows day by day" [6].

In his subsequent "Contemporary City" Le Corbusier addresses issues of transport congestion, densities and pollution in the city by proposing a vertical green city. A city with green lungs, high rise accommodation removed from the emissions of the efficient road networks. However, the proposal is utopian in that it is sharply discontinuous with respect to the existing urbanisation and its social, economic and cultural roles, although it embodies interesting environmental aspects.

The discontinuity of the historic city has been adopted by the 'Decentrists' through the zoning of activities, and is typified by the American suburban sprawl. This has resulted in the de-urbanisation and anonymity of cities evocatively described by Virilio [7]:

"Where the polis once inaugurated a political theatre, with the agora and the forum, today there remains nothing but a cathode-ray screen... This 'cinematism' conveys the last appearance of urbanism, the last image of an urbanisation without urbanity... Contrast, differentiation and opposites are fading due to suburbia...".

The lack of interchange and juxtaposition between the public and private spheres has reduced the urban character of cities to one of networks for movement, limiting the availability of public spaces as places to be in, in favour of transport systems to connect disparate zones. This dispersal has been made easier by the increasing use of the private car, and results in higher transport energy use and emissions.

Urban density

The concentration of activities and people in cities is often the perceived main source of environmental problems. However, such concentration can have environmental advantages achieved through the sharing of resources. Furthermore, without a degree of density there would be no city.

The absence of energy constraints during this century has allowed for the increasing dispersal of activities and decreasing densities. The lower densities of such developments increases physical separation and diffuse dispersal, making mass transport difficult, and results in increased private vehicular traffic. However, in dispersed developments with greater solar access, solar design will have greater potential. Nevertheless, it can be demonstrated that the energy balance can be in favour of urbanisation. This is not the case for office buildings, where the noise in particular is perceived as the main reason for increased demand of air conditioning, contributing to increasing energy consumption.

Low densities encourage the use of the car. The intensification of land use can reduce transport resources, and because of the shorter distances involved, there is the potential for increasing the use of bicycles or for walking.

It can be shown that cities of a high density, such as for example Hong Kong, have a far lower transport energy demand than low density cities such as for example Houston [8]. However, it is not yet clear to what extent density is the cause, and increased energy use is the effect. For instance, it can be argued that where private car use is less – due to for example economic conditions – cities are denser. Interestingly, historic European cities, such as Paris, lie at a notional 'optimum' –

achieving moderate energy use for modest densities – whilst enabling a rich city centre life.

Practice (Berlin, Shanghai, Linz and Manchester)

A number of recent large-scale urban design projects have been carried out that attempt to address the issue of urban sustainability. It is worth briefly mentioning such projects, not because they represent the best approach, but because there are lessons to be learnt from them.

These projects are major urban master plans on vacant, only sometimes 'brownfield' sites, and thus immediately raise questions about their sustainability. Issues of sustainability are raised because the basic strategy is almost in principle not sustainable – any major development will normally consume more resources in the form of energy, materials, water, land, etc., and will generate more transport than no development at all. However, no development may be economically unsustainable.

Three examples of this are the Potsdamer Platz projects, Berlin (master plan by Renzo Piano/Kolbecker), the Shanghai Central Business District (Richard Rogers Partnership) and the Linz Solar City Project, Austria (co-ordinated by Thomas Herzog). All have been subjected to environmental analysis. Without going into specific details about each project in this paper, a number of general strategies have come out of the projects:

- Compact plans with maximum walking distances of 300 meters to the nearest public transport node to minimise reliance on private car use.
- Mixed uses (housing, commercial, leisure, etc.) to encourage a local and economically sustainable use of resources and facilities.
- Localised energy supply (e.g. combined heat and power, renewables, etc.), waste and water recycling for increased efficiencies of scale.
- Integration of vegetation for physical benefits (shade, evaporative cooling, wind shelter, etc.), ecological advantages (increased local bio-diversity) and psychological well-being (pleasant views, contact with nature, etc.).
- Integrated and efficient public transport infrastructure from pleasant pedestrian and cycle routes, to tram, light rail and national transport networks.
- Shallow plan buildings organised around 'clean' and 'quiet' courts, streets and squares, to enable passive design strategies (daylight, natural ventilation, solar gains/shading, etc.).
- Massing of buildings to ensure equitable access to light, air and views.

The above findings, particularly the first two, are based on broad literature reviews, as opposed to analytical research, and tend to offer potential rather than ensure performance. The range and complexity of the strategies, and their interdependence, makes it difficult to analyse objectively and to separate cause from effect. The result is that alternative arguments and examples can be found, and the issue becomes one of persuasion or conviction.

None of the type of projects mentioned above address the nature of the existing city and its environmental problems – vacant or brownfield sites, transport congestion and local pollution, economic or social blight, etc. A recent project in Manchester demonstrates another approach to the problems. A project by 'Urban Splash' (an environmentally aware developer/client organisation) is a response to the increasing pressure for urban housing by refurbishing a redundant warehouse in the city centre. It some ways it is not unlike the New York loft projects. The combination of mixed-use development and the reuse of existing urban buildings provides an interesting alternative case study to the major urban reconfigurations described above. It is also a reflection of a trend and demand, particularly strong in Manchester (and one or two other cities), for urban living as an alternative to suburban life. The social and cultural advantages for certain types of people are evident, even if the environmental benefits have not been quantified. Thus again the principles are intriguing but not validated.

It would seem clear that research has a potential role to play here, in order to establish what the underlying mechanisms for sustainable development are, and to offer analytical design tools.

Research (metabolism of the urban block)

1

Broadly speaking there have been two approaches to environmental research at the urban scale:

- The study of complete and existing cities: At this large scale, transport is clearly a critical factor that shapes our current cities and affects the urban environment. It has key energy use, air quality and noise implications. Transport is often highlighted as the main problem to be addressed. Owens [9] for example explores the possibilities of minimising energy use of transport at the city and regional infrastructure, and buildings at the micro-scale. The intermediate scale of neighbourhoods is not seen as offering any significant possibilities.
- Theoretical proposals: Strategic urban design responses are the focus of Golany [10] and others. The approach is to categorise climate and the key environmental issues, and then propose an 'ideal' urban morphology. The implication is for a radical or revolutionary approach to the design of new cities, as opposed to remedial work in existing cities. Golany [10], Mänty [11] and Jacobs [12] go on to acknowledge the critical importance of the urban neighbourhood, but quantitative research at this scale is complex and scarce.

The approach adopted by the Martin Centre [13, 14] is to analyse a part of a city – that which could typically be defined as an urban block or neighbourhood within the wider city context. This approach is being developed, validated and applied in a series of EU funded projects at the Martin Centre: most recently 'Project ZED' and 'PRECis'. The technique adopted is to categorise the physical geometry and assess the consequence of this on environmental characteristics. We have begun to establish the generic nature of the interrelationship between the urban geometry and the environment - in particular the energy use of buildings. This suggests that if a piece of city can be geometrically categorised using image-processing techniques, then the environmental characteristics can be deduced without recourse to complex environmental simulation. The other implication of this work is that it can assess whether significant environmental improvements can be effected by limited remedial or evolutionary changes to an existing city at the neighbourhood scale.

This work is focussed on questions of urban texture, and currently provides a technique to assess the implications of form (not fabric, systems, occupants behaviours, etc.). Nevertheless, form is a central urban design parameter and can be used as a framework for a range of related questions, such as the influence of mixed uses, refurbishment, energy supply (and the potential of renewables), transport data input, etc. Form is thus an anchor for wider questions, specifically at the level of urban blocks.

The need to address the dynamics – socially, politically and environmentally – of the urban block or neighbourhood is critical. Only at this level does it seem possible to integrate the range of issues that relate to questions of architecture and planning. If one gets too close, and studies individual buildings, one misses the critical interdependence and essentially urban perspective. Taking the city overall, and the rich socio-political dimensions of human interactions, and their relationship to environmental characteristics, are neutralised. It is this 'metabolism of the urban block' that is the lifeblood of the city.

Policy and perception (the UK Urban Task Force)

New modelling and analysis techniques are being developed, but in the meantime, policy decisions are being made on the basis of historical facts, precedent and a 'wish-list' of measures. For example, the successes of the Manchester example above, amongst others, are often quoted as exemplars of an urban renaissance, embodied in the 'Mission Statement' of the UK Urban Task Force report [3].

"... practical solutions to bring people back into our cities... a new vision for urban regeneration founded on principles of design excellence, social well-being and environmental responsibility..." [3]

However, it is evident that the current situation of Manchester is almost unique. It has a rapidly growing student population, currently about 80,000, and as a result a thriving youth (and bar/café) culture. This in turn has enabled Manchester to 'reinvent' itself as an attractive place to live, stimulating economic investment and development (particularly of urban housing as in Castlefield). Such a specific set of conditions has enabled the particular solutions, but what remains unclear is to what extent they are applicable, viable or appropriate for other contexts. However, as one model it brings useful lessons and points towards possibilities in response to a particular context.

A major effort of the 'Urban Task Force' is to alter people's perception of urban living in the UK. By increasing urban populations through the development of existing 'brownfield sites' it is imagined that there is the opportunity to increase "the quality of life and vitality that makes urban living desirable" [3]. A causal link is suggested but not demonstrated making opposing views difficult to refute (e.g. increasing urban density will increase urban traffic). This is where research related to the dynamics of the urban neighbourhood is valuable, as opposed to relying on precedent or hope, however much consensus there may be about the underlying ideas.

Some of the key statements for urban development that can be extracted from "Towards an Urban Renaissance":

- Recycling land and buildings: 60% of new dwellings to be built on brownfield sites over the next 25 years
- Improving the urban environment: quality of design; compact development; investment in public transport, pedestrianisation and cycling
- Achieving excellence in leadership, participation and management: local powers, resources and democratic legitimacy

In summary:
"Towns and cities should be well designed, be more compact and connected, support a range of diverse uses within a sustainable environment which is well integrated with public transport and adaptable to change" [3].

The above statement has much in common with the conclusions made from the practice projects described earlier, but makes no reference to the need for rigorous research to underpin the recommendations. Despite this, it is clear that the political will is to a large extent, and needs to be, in place to encourage sustainable development. Historically, policy implementation has not always shown to be the best route, as is perhaps best typified by the urban 'regeneration' projects of the 60's. There is clearly a wish for visionary policy, but perhaps equally a need for an analytical and responsive approach. The role for research here is evident, both to assess historical and contemporary precedent and to offer objective analysis techniques.

Conclusions

There is a broad consensus across the related strands of practice, research and policy with respect to the key 'ingredients' for sustainable urban development – although contrary arguments do exist. However, there is a lack of rigorous integration between each sector, which results in undermining the case for sustainable strategies. In particular, the potential contribution of research has hardly been brought to bear on this relatively new field of investigation, and there is perhaps too much reliance on empirical information in favour of (or because of a lack of) analytical methods.

I invite the delegates of this meeting to come and debate these issues in the upcoming PLEA and RIBA Conferences entitled "Architecture + City + Environment" and "City2K" respectively [1].

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Low Energy School Buildings
Passive/active solar design experiences.

P.C.Grindley
° 7 Fowlmere Road, Foxton, Cambridge CB2 6RT, United Kingdom.
Tel: +44 (0)1223 520 706; Fax: +44 (0)1223 520 704;
E-mail; P.C.Grindley@bizonline.co.uk

Abstract

This paper reviews some examples of passive solar buildings, which were designed to take advantage of the beneficial effects of sunlight. The main findings of a study of passive solar schools built in the U K were that: schools with passive solar features need not cost more than ordinary schools, and a good passive solar school design can result in at least a 10% reduction in energy use. The design recommendations resulting from computer simulations are also presented, as are the subsequent actions taken by the UK Government to implement these findings, and reconsider the subject of recommended minimum ventilation rates in schools. It concludes that passive solar buildings using renewable energy sources have already demonstrated that it should be feasible to achieve sustainable buildings.

Acknowledgement

The Department for Education and Employment (DFEE) in the UK provided financial support for the monitoring and computer modelling studies on the passive solar schools referred to. The DFEE also processed the data on capital costs for thirty-six passive solar schools, and the use of energy in thirty-one of them.

Introduction.

From ancient times, sunlight was the primary source of light in buildings. Both diffuse daylight and direct sunlight have been used to heighten the awareness of form, and create a sense of occasion, surprise and delight in buildings. Examples of this were : the general exclusion of daylight, and carefully timed admission of beams of direct sunlight in some temples of ancient Egypt; the subtle use of optical illusion, as with the columns of the Parthenon seen in bright sunlight; the use of the occulus skylight and concealed clerestorey lights in the buildings of ancient Rome, and the dramatic effect of the light from the stained-glass windows of Medieval and Renaissance cathedrals, and early in the twentieth century, Corbusier's chapel of Notre Dame du Haut at Ronchamp.

The Crystal Palace in London was built in iron, timber, and glass for the great exhibition of 1851. With the subsequent development of steel and reinforced concrete technologies, the modern movement in architecture was free to explore the possibilities of enclosing large volumes in glass, and visually linking interior and exterior spaces, even on a small scale of enclosed space. This often produced unacceptable internal environmental conditions. Kinetically variable facades have been used, which were designed to adapt to alter the transmittance of sunlight with time of day. Examples of these are the wholly-glazed geodesic dome designed by Buckminster Fuller for the American Pavilion at Expo 67, Montreal. This had computerised sun-blinds to control the tendency for overheating of the interior and critical cooling loads, and the Institute du Monde Arab, designed by Jean Nouvel, and built in Paris during 1981-87. This building has a glazed curtain-wall, overlaid with a pattern of frames, incorporating motorised computer controlled filters to vary the admission of sunlight at predetermined times of the day. The visual patterns are a decorative motif, which allude to Arabia.

Problem

About half of the total annual CO_2 emissions in the United Kingdom (UK) relate to the use, which is made of buildings. Architects have always been interested in the interplay of sunlight with the form of their buildings, and with the visual interaction between indoor and outdoor spaces. However, with some notable exceptions, they neither appear to have always been interested in the thermal performance of their designs, nor to have understood fully the effect, which their design decisions had on the internal environment, and comfort of occupants. The result in the United Kingdom was a legacy of over-glazed and under-insulated buildings, which gave rise to complaints from occupants, who suffered the effects of overheating and visual discomfort from glare, and from building owners, whose fuel bills were significant.

Following the oil crisis of the 1970's, the conservation of fuel was recognised as an important design consideration. Regulations were introduced, which increasingly required improved thermal performance for buildings. Separate guidelines were issued for school buildings. However, even in school buildings, which are predominantly used during the daytime, and have traditionally recognising the importance of daylight, the use of electric lighting was increasing. This was despite the installation of more efficient fittings and lamps, and an overall reduction in the gross areas occupied nationally.

UK School buildings

The character of teaching spaces in schools reflect ideas about the curriculum, educational practice, architecture, building construction and regulation. For most of the period from the late nineteenth century there have been significant changes. A noticeable trend in the UK has been that, as the 20^{th} century progressed, new schools admitted more daylight and direct sunlight to the teaching spaces than earlier examples. This peaked in the late 1970's, and the trend either reversed or remained static during the 1980's and 90's.

School buildings designed in the period from the mid 1940's to the late 1970's reflect the imposition of mandatory minimum standards and a preferred target level of daylight in teaching areas. Most of these buildings have predominantly glazed facades.

Those of the 1950's and 1960's were mainly built of relatively lightweight, flat-roofed form of construction. The post-war requirement being low initial cost and rapid erection to deal with an expansion of basic needs at a time of shortages of materials, finance, craft skills, and lead-time before occupation. This was also a time of relatively low energy costs. With some significant exceptions, little thought was given to thermal performance, climate modification, or user comfort. Consequently, most of the UK school buildings of the 1950's and 1960's tended to be thermally inefficient. They were subject to substantial heat losses during the heating season, and excessive overheating and glare from solar radiation gain at other periods.

The oil crisis of the 1970's was a rude awakening. Escalating energy costs gave rise to increased interest in the thermal performance of buildings. Regulations were introduced to achieve improved thermal performance of the external elements of buildings, and energy conservation had to be considered as a design factor. The previously mandatory standard of daylight in teaching areas in UK schools was relaxed to permit smaller windows and supplementary electric lighting as a means of meeting the required illuminance on the working plane. It was assumed that these measures would be more energy efficient. A design note was issued (1), which set targets and performance requirements for environmental design and fuel conservation in education buildings. A version of this (2) was current, but in need of further revision, at the time that this passive solar schools study was undertaken in the UK.

Today, many new school buildings are better insulated, and have more moderate space heating demands. However, the environmental performance during the rest of the year is often poor.

In the early 1990's, the environmental guidelines (2) were being criticised, because:
(i) The beneficial effect of a passive solar design approach was not considered.
(ii) The requirement for fresh air lacked credibility.
(iii) The dynamic performance of buildings was not assessed.
(iv) The design procedures forced the provision of deep planned, low aspect ratio buildings.

A problem in terms of CO_2 emissions was that, although by the 1990's, UK schools had much improved thermal performance, and were primarily occupied during the daytime, the use of electric lighting then represented a significant proportion of their energy loads and CO_2 emissions. The use of electric lighting had been shown to have increased significantly at a time when both the number of maintained school places had been falling, and more energy efficient fluorescent light fittings had replaced much of the earlier, tungsten light fittings(3). At that time, the design procedures adopted in the official guidelines were weighted towards a low aspect ratio, deep planned, design solution. The requirement to make good use of the available daylight appears to have been overlooked.

Passive solar school buildings.

In contrast, a good passive solar design aims to provide thermally efficient buildings in which internal spaces have ample daylight, take advantage of available useful solar gains, and are also designed to avoid or minimise overheating.

The first passive solar school in the UK was St George's, (later renamed St Mary's and subsequently replaced following extensive fire damage) and was built in 1961 at Wallasey. It was designed by A.E.Morgan, to relatively good insulation standards for the time. It featured a large, southerly aspect, glazed solar collector wall. This school demonstrated the potential of such a climate responsive design. Space heating demand was in practice met by solar and internal gains from occupancy and electric lighting. Glare was reported as a problem, and the air quality was judged to be poor as a result of inadequate ventilation. The extensive use of tungsten lighting as a source of both heat and light was also criticised(4).

Passive solar school buildings are not commonplace in the UK. However, many commercial buildings have sun-spaces and other features associated with passive solar design. The popularity of these solutions, and their aesthetic appeal to designers, has led to them being used in school design.

If passive solar schools were adopted more generally in the 1990's, then the guidelines for schools would need amendment. It was however considered that, with improved insulation standards, this was unnecessary and that for passive solar school buildings:

(a) Unjustifiable additional capital cost might be incurred;
(b) There would be an insignificant benefit in terms of energy consumption, and
(c) There was a risk of discomfort from employing sun-spaces and other passive solar features.

The UK Government Department for Education and Employment (DFEE) therefore commissioned Cranfield University to carry out a survey to identify the schools in the UK, which have passive solar features. A DFEE steering committee selected six schools for environmental monitoring, and dynamic computer simulation studies.

Further research was subsequently commissioned from Cranfield University to undertake additional computer simulation and analysis, and produce a design guide. This work was commissioned specifically to enable a building bulletin(5) to be published to explain and illustrate the principles and features of passive solar design, and present results of the research undertaken, together with an assessment of selected case studies of passive solar school buildings in the UK.

Construction cost appraisal

Tender costs for thirty six passive solar schools were investigated. The costs were obtained from published sources and Local Authorities. All prices were adjusted to be correct to the fourth quarter of 1992 as shown in Figure 1.

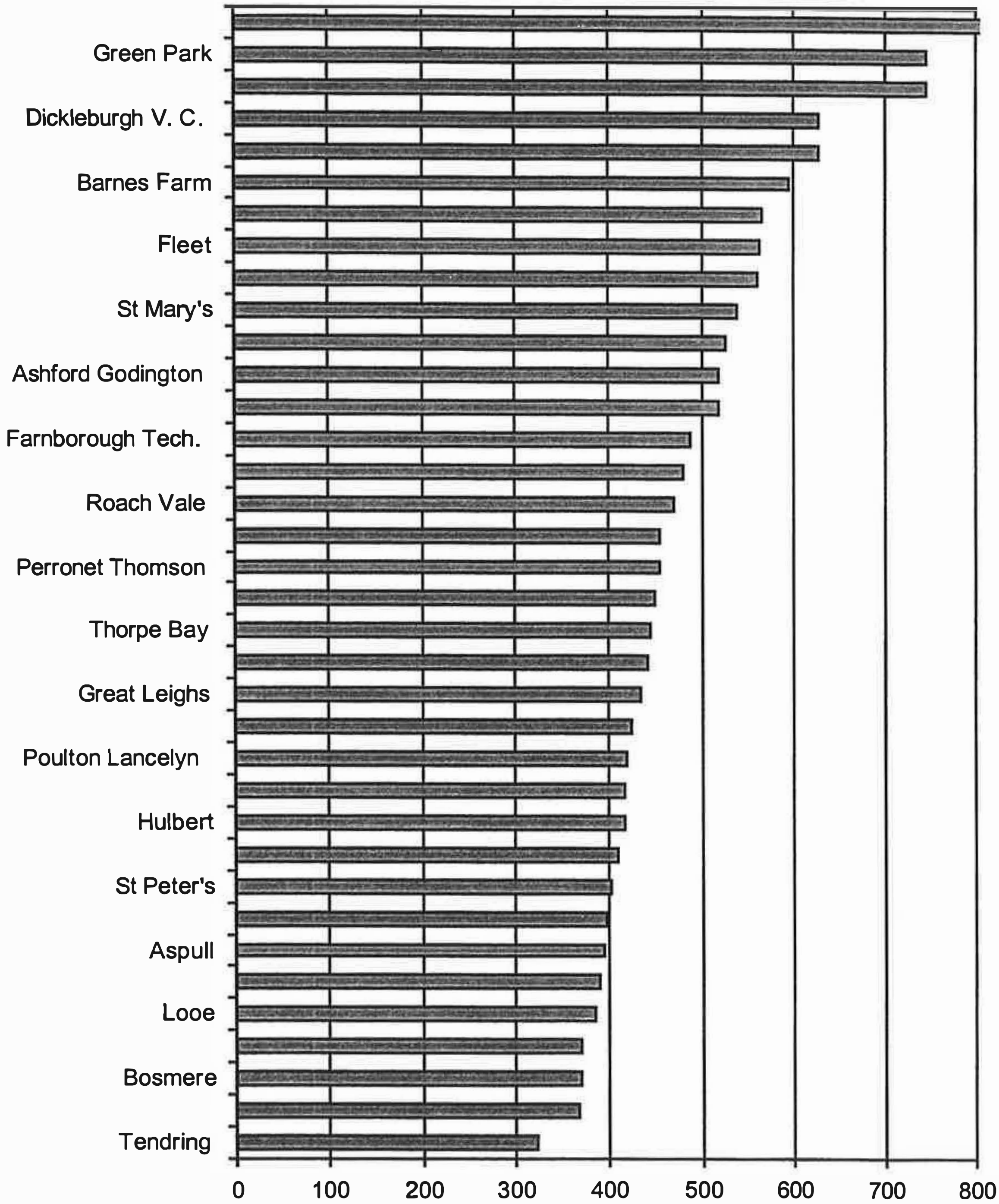
The average cost of the passive solar schools looked at was £461/m^2.

This compared well with a national average cost (for the fourth quarter of 1992) of £476/m^2 for 918 new schools and major extensions built between 1986 and 1992.

However, while some passive solar schools cost a great deal more, most are of a similar cost to ordinary school designs.

The costs of the passive solar schools were generally within 10% of those recommended by the DFEE for new school buildings. On average, the passive solar schools looked at cost less than the cost norm for ordinary schools.

Figure 1 Passive solar schools, Capital costs/m ^{2}



Cost at 4Q92/m^2 Corrected for location

National interquartile average cost £476/m^2
Passive solar interquartile average cost £461/m^2

Energy use appraisal

Energy consumption was regularly monitored for many of the passive solar schools looked at. To analyse the energy performance of the buildings, the actual annual energy consumption value (AECV) was worked out from known consumption figures converted to primary energy units, as defined in the guideline(2) , for 25 of the passive solar schools. These were compared to AECV average monitored values for UK secondary schools (excluding kitchen use) of 332kWh/m^2, and 302kWh/m^2 for UK primary schools, calculated using the figures in CIBSE guide volume F Table 2.16.

The DFEE guideline(2) maximum for a 1400m^2 primary school was 300kWh/m^2.

In order to assess the validity of this guideline(2) energy consumption method, the calculated AECV, predicted by design teams, and available for eighteen of the schools looked at, were compared both with the guideline maximum and the actual energy consumption AECV.

It can be seen from Figure 2, that, the actual AECV's for all the passive solar schools looked at were below the guideline(2) maximum of 300kWh/m^2, and in most cases were well below. The variation between predicted AECV and actual AECV is evident, indicating a problem with the guideline method of calculating AECV. The guideline method did not specifically allow for beneficial solar gain.

It should be noted that the extent to which the passive solar features of the studied schools influence the overall school energy consumption varies from example to example. However, it was possible to conclude that, if a passive solar school is properly designed, then the school will be more energy efficient than ordinary school designs.

Environmental Monitoring.

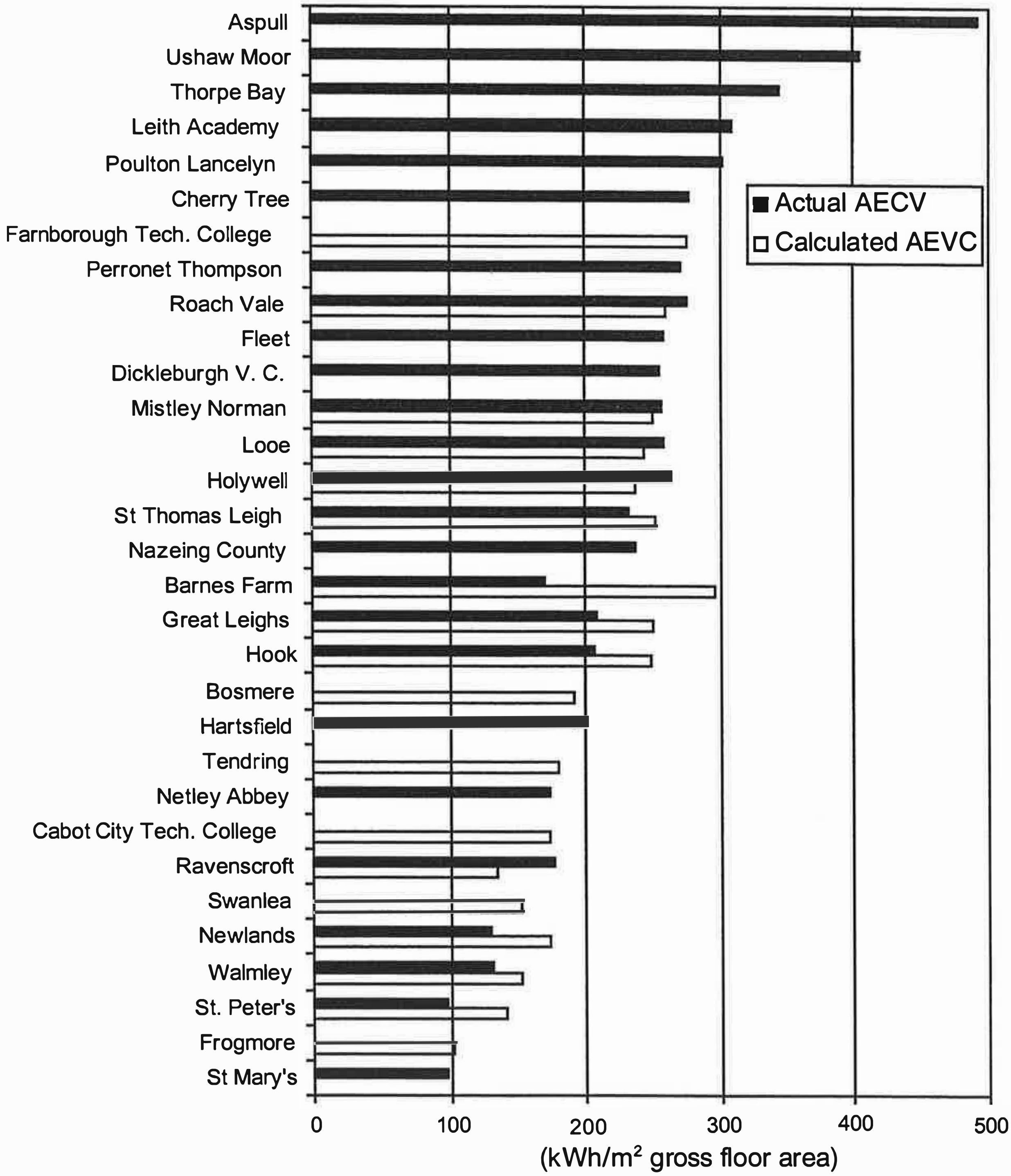
Six schools were monitored. These included two single storey buildings with a central atrium. Both were located in the South East of the UK. One was newly built of traditional heavyweight construction, and the other was a refurbished system built school of relatively lightweight construction. Briefly both schools had classrooms either side of a central atrium, which provided both accommodation and a circulation link with other spaces in the school. The newly built school had an unheated atrium providing relatively low cost additional space. The refurbished school had a heated atrium, and used this as teaching space.

The monitored temperatures demonstrated that, the unheated atrium met comfort requirements during the period of occupancy on a cool December day with some sunshine. (Figure 3.) However, the unheated atrium would be unusable for teaching purposes due to being uncomfortable on some winter days, totalling about one month each winter.

Atria must always be provided with reliable and adequate means for venting excess heat. In both schools, opening lights were incorporated in the atrium roof.

During occupancy, both atria tended to overheat before the roof vents were opened. This was because the occupants delayed operating the roof vents until the space was significantly overheated.

Figure 2 Annual consumption of primary energy



Average monitored secondary 332 kWh/m^2
Average monitored primary 332 kWh/m^2
DN17$_{(2)}$ maximum for 1400m^2 primary 300 kWh/m^2
Average of passive solar schools 206 kWh/m^2

Figure 3 Monitoring Comfort
Barnes Farm: Cool, cloudy, occupied day.

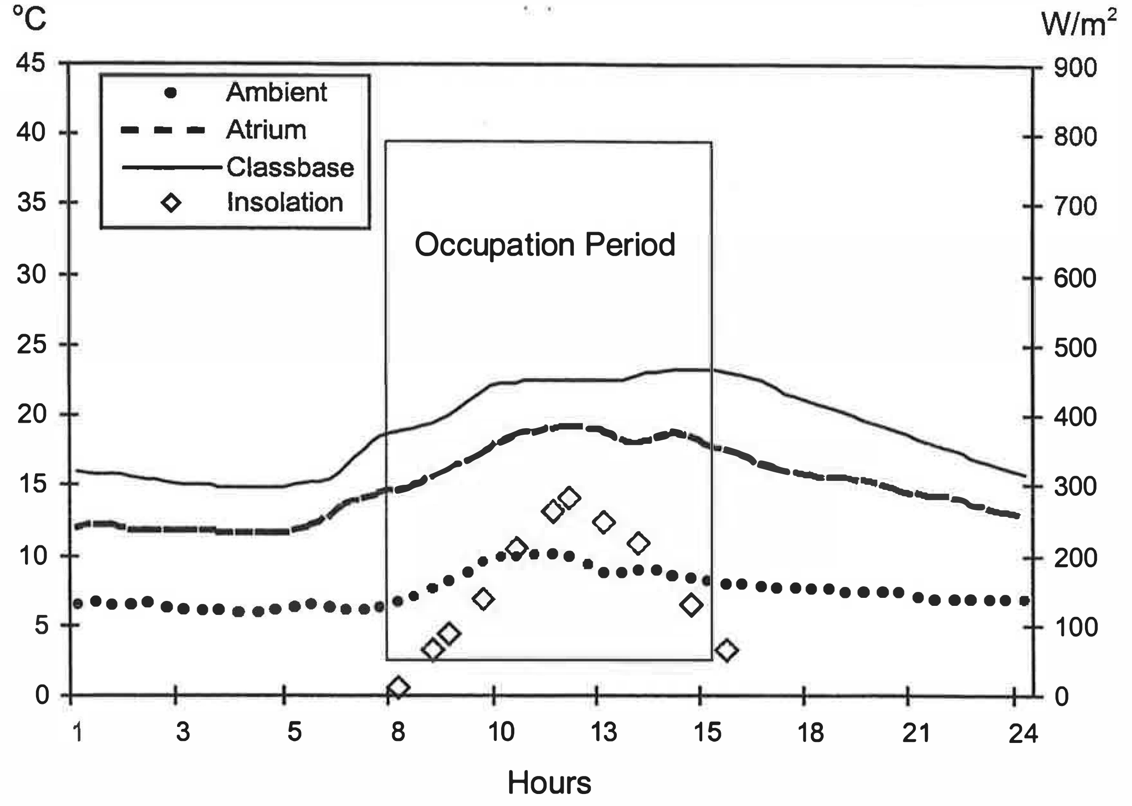
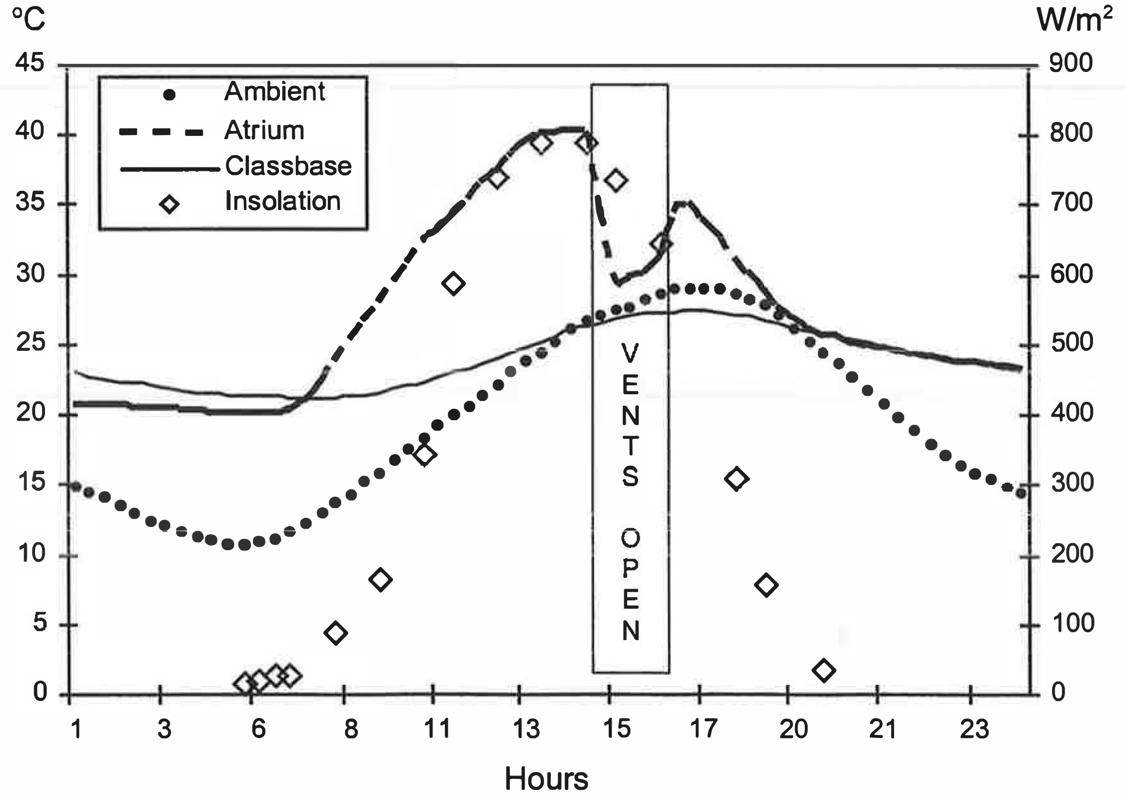


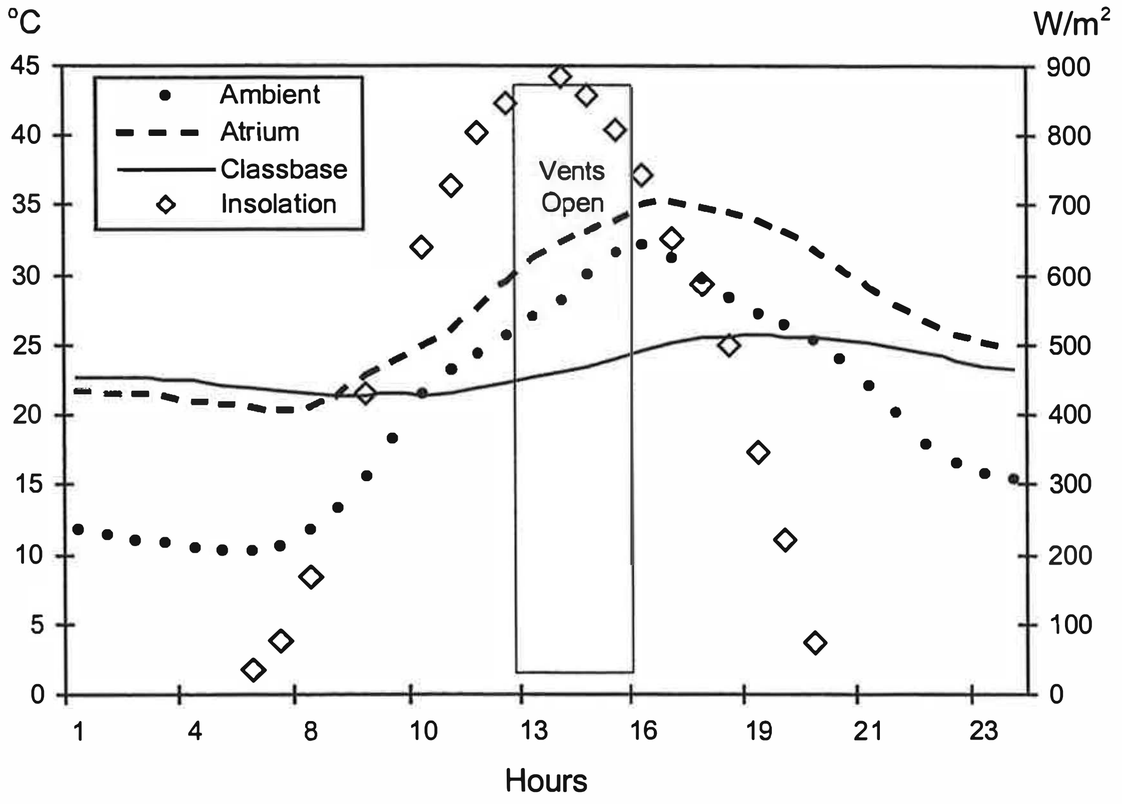
Figure 4 Monitoring Comfort - Venting of Atrium
Barnes Farm: sunny, occupied day.



In the newly built school, the opening of the roof lights had an immediate impact on internal temperatures, reducing them immediately, almost to ambient temperature. (Figure 4.) In this atrium, approximately one third of the glazed roof area could be opened at ridge height. These opening lights were operated as one, using a reliable rack and pinion mechanism. This was set to manual control during the monitoring period, but could operate automatically if required.

In the refurbished school building, the opening of the roof lights had a negligible effect on internal temperatures. This school had only a small number and area of opening lights, which unfortunately were operated by unreliable cord-operated gearing. (Figure 5.) Glare was also a point of concern at this school.

Figure 5 Monitoring Comfort - Venting of Atrium
Hook: sunny, occupied day.



Computer simulations

Several aspects of the thermal performance of schools with sun-spaces were simulated using a dynamic thermal model. The results on orientation and atrium width of the two schools with central atria are of particular interest. The annual energy demand predicted for each change of orientation in steps of 15 degrees showed a negligible effect for changing the orientation of the building. This is because the major part of the useful solar gain is via the incidence on the atria from above. The axial orientation of the atrium is unlikely to affect the useful solar gain significantly. The atrium solar gain dominates the effect of gain and losses from varying the aspect of other fenestration. This would seem to indicate that a school with a central atrium could be an advantage on sites where a southerly orientation is not feasible for the main areas of normal fenestration.

Computer simulations and parametric analysis were undertaken in respect of the width of atrium in the two selected schools with central atria. These predicted that overheating of the atrium in the heavy-weight construction of the newly built school, which had a 6.2 metres wide atrium, would become critical at an atrium width exceeding 7 metres.

The equivalent computer simulation results for the heated atrium of the refurbished light-weight construction school predicted the problems of overheating revealed by the monitored data. The degree of overheating was predicted to increase with atrium width. When the atrium is heated, the heat loss also increases with atrium width.

As a general rule, single storey atria should be no more than 7 metres in width. The lower limit on width is determined by space utilisation factors.

A series of computer simulations were carried out to assess the direct gain consequences of varying the extent of classroom fenestration, shading and orientation on energy use, overheating, daylight levels and electric lighting use.

Case studies

Seventeen of the passive solar schools looked at were described in detail and appraised in the design guide published in 1994(5).

Conclusions

The main design findings of a research study of schools built in the U K(5) incorporating some passive solar features were that:

The successful design of a passive solar building requires a holistic approach. Their design philosophy should respect both the climate, and the surrounding external environment, and select those environmental elements, which best compliment the nature, use, and occupancy of the building, whilst filtering out those of a less desirable nature. Designers therefore need to consider building physics as an integral part of their holistic approach to design, and assess the environmental impact of their design ideas early in the development of a design solution.

The case studies examined demonstrate that a passive solar feature simply incorporated in a design without this approach may not work as desired and may cause significant problems for the occupants.

The main findings on the cost of construction and energy use of this study of passive solar schools built in the UK were:

(a) schools with passive solar features need not cost more than ordinary schools, and
(b) a good passive solar school design can result in at least a 10% reduction in energy use.

The conclusions of the computer simulations carried out for the UK climate on were:

(i) For significant winter solar gains the glazed apertures should face within 30^0 of due South.
(ii) The axial orientation of a building with a central atrium, has little effect on its energy usage.

(iii) The width of a single storey atrium should not exceed 7 metres. This is to prevent excessive heat loss in winter and overheating in summer.

(iv) To prevent summertime overheating, which can be a major problem in atria and conservatories, around 20% of the roof area should be capable of being opened.

(v) Overhangs of more than 300mm over windows serve little purpose in terms of shading or improved daylight.

The results of this study demonstrated the need to amend the existing environmental design guidelines for UK school buildings. This required changes in government policy.

Sequel

The report of this passive solar schools study was published by DFEE as a design guide(5).

The existing environmental design guidelines(2) were reviewed by the DFEE and quickly amended(6).

The DFEE then significantly revised their guidelines for environmental design, and published it in 1997 as a building bulletin (BB87)(7). It gives constructional standards for new school buildings. It includes sections on acoustics, lighting, heating and thermal performance, ventilation, hot and cold water supplies, and Energy (CO_2) ratings. It encourages architects to develop a holistic approach to design, considering building physics as an integral part of their design, with early input from energy and environmental specialists. BB87 is currently out of print, and the opportunity is being taken to revise the recommended standards as far as possible. The passive solar gain calculation has already been revised and can be downloaded in the revised section F, together with a downloadable Excel spreadsheet containing the revised energy rating calculation from the DFEE web pages at:
www.dfee.gov.uk/schbldgs/environment.htm

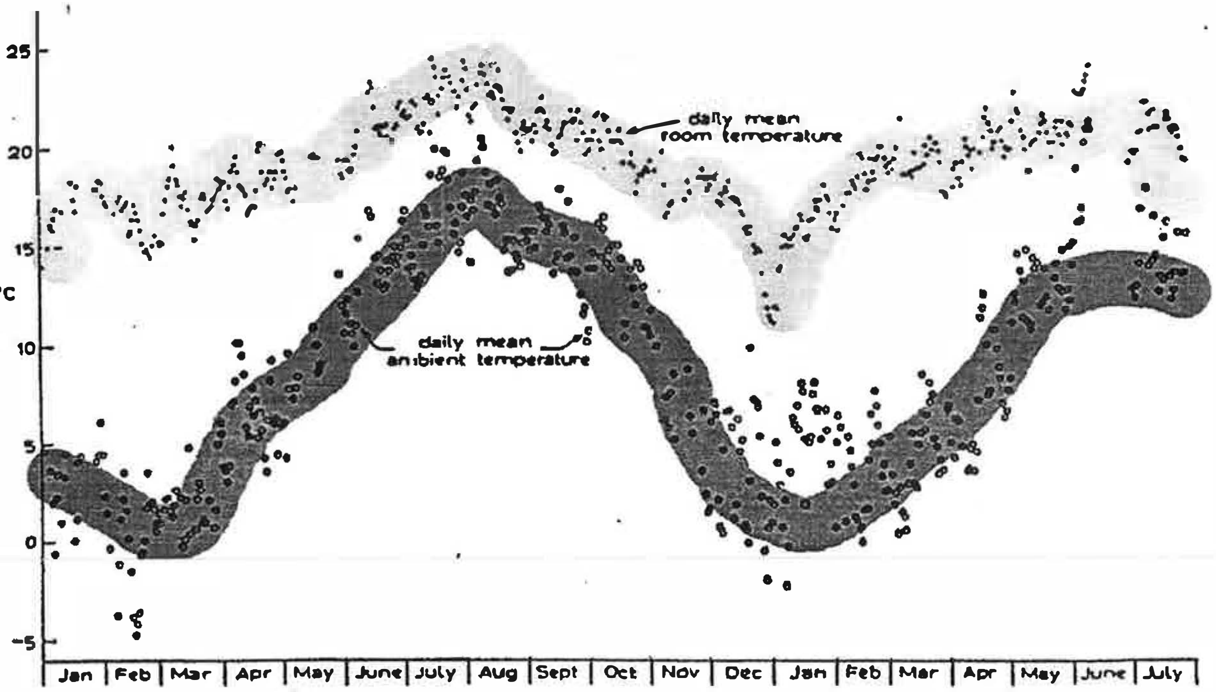
Ventilation standards are being reviewed by DFEE in the light of a large amount of international research, which has been published on the subject. Carbon dioxide levels as an indicator of indoor air quality are already specified as a design parameter for classroom ventilation in many countries.

The Challenge

The challenge today is to design buildings which are sustainable for the future both in terms of the materials used in their construction, and the use of renewable energy sources.

Essex County Council in the UK commissioned Allford Hall Monaghan Morris to design a sustainable school building, which has been reported in the architectural press. The design team undertook research in order to source as many recyclable, low embodied energy, environmentally preferred materials as possible. However the article is critical of long haul supplies of products from China, Germany and Sweden. An approach which the designer reportedly "acknowledges as fundamentally flawed(8)." Energy targets and costs in use are not reported.

There are problems with the existing examples of UK passive solar schools. Nonetheless the building of the St George's school at Wallasey in 1961 was a milestone in pioneering design. It demonstrated the potential, as can be seen in Figure 6. Which shows mean daily ambient and internal temperatures throughout the year. It was reported that the estimated heating sources were 50% solar, 34% incandescent lighting, and 16% gains from pupils(9).



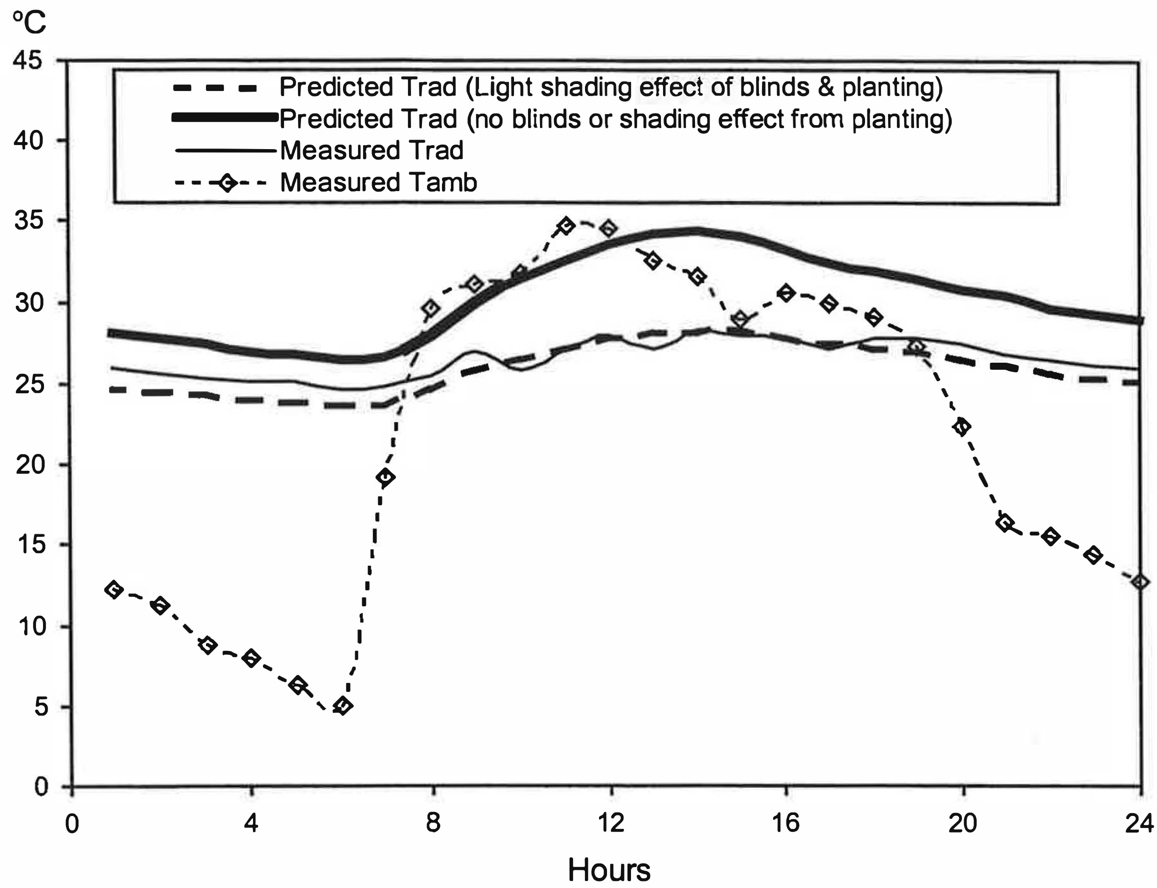
Each dot or circle represents the mean temperature for the day, based on up to 72 daily values. Dots denote indoor air temperature and circles outdoor air temperature.

TEMPERATURES IN ST MARYS R.C. COLLEGE

Figure 6. Mean daily ambient and internal temperatures - St George's School, Wallasey, (renamed St Mary's RC College).

A more recent study of a sustainable daytime use office building in New Mexico designed by M Reynolds, demonstrates the feasibility of achieving a zero CO^2 building even in a climate with extremes of temperature. Figure 7 (10). The local climate varies from +40^0C to -40^0C during the course of a year with large diurnal temperature swings. The building is constructed using recycled materials, earth, timber and glass. It has a large, southerly facing, fully glazed facade to take advantage of direct solar gain. It uses photo-voltaic solar cells for power generation, with both alternating and direct current distribution, and solar collectors for water heating. Rainwater is collected, treated and stored. Waste-water is recycled as a grey-water system. Monitored data showed that when the ambient temperature ranged from 4^0C to 35^0C, the interior of this day-time use office building was found to overheat marginally, since the comfort norm locally is considered to be 27^0C. Using a dynamic computer simulation, this building was predicted to achieve comfort conditions during the working day for most of the remainder of the year. This finding accorded with what the occupants reported. There are also numerous examples of the domestic use of this type of building design, which are not mains connected and use renewable energy sources, apart from LPG for cooking.

Figure 7 Mean Radiant and Ambient Air Temperatures



These isolated examples have been developed over time on a trial and error basis, without the use of computer modelling tools available today. They demonstrate the feasibility of achieving sustainable development. More integrated residential developments have since been planned.

The first sustainable elementary school of the Netherlands is currently being designed for a site at Castricum. This new school project comprises a mixed development with housing using the site of an existing school.

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