UNIVERSITY OF EXETER

Annual Report 2014

Centre for Energy and the Environment




About SWEEG

The South West Energy and Environment Group (SWEEG) is a collaborative research partnership between public sector organisations in the South West which aims to share information and research on energy and environmental issues in the built environment.

As a coordinating member, the Centre for Energy and the Environment (CEE) carries out technical research for the group. All research completed by the Centre is disseminated among SWEEG partners and work of wider interest is published in technical and academic journals. A list of this year's publications can be found at the end of this report. Further details about the Centre and SWEEG are available at www.exeter.ac.uk/cee.

Current SWEEG Members

- Cornwall Council
- Devon and Cornwall Police Authority
- Devon County Council
- East Devon District Council
- Exeter City Council
- Mid Devon District Council
- Plymouth City Council
- Royal Devon & Exeter NHS Foundation Trust
- Teignbridge District Council
- Torbay Council
- University of Exeter

Organisations wishing to enquire about SWEEG or commission work from CEE should contact:

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University of Exeter
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Rennes Drive EX4 4RN

Tel: 01392 724143

Web: www.exeter.ac.uk/cee

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Front cover

Marsh Barton Energy from Waste facility, Exeter

image: www.recycledevon.org


Introduction

About the Centre

The Centre for Energy and the Environment has been working with government, local authorities, other public sector organisations and businesses for over 35 years.

As a research group within the University of Exeter, the Centre is uniquely placed to provide bespoke research which can help reduce carbon emissions and energy consumption.

Our expertise is varied and covers all aspects of the built environment including:

- Sustainable building design
- Improving efficiency in existing buildings
- Policy in energy, buildings and the environment
- Carbon reduction strategies
- Adaptation to climate change
- Renewable and community scale energy
- Thermal modelling and daylighting
- Acoustic design
- Transport policy
- Waste

Research at the Centre ranges from 3 to 5 year Research Council programmes to shorter applied projects in both the public and private sector. Working with the Centre also provides access to the wealth of academic expertise within the University.

Work for SWEEG partners can be highly strategic or technical in nature, but the Centre also has the ability to respond quickly and flexibly to new challenges. The Centre retains a pro-environmental outlook but is impartial and objective in the research it carries out. Contract research and consultancy are also undertaken in both the public and private sectors.

Staff from the Centre also teach within the University and can deliver bespoke CPD training programmes or provide academic supervision for Knowledge Transfer Partnerships with industry.


The Centre takes an active interest in the technical, strategic and policy aspects of energy developments in the region and regularly engages with key players in the sector. At a recent visit to Fullabrook wind farm in Devon members of the group met with Rory Jordan, the project manager for Devon Wind Power. Rory was involved with the project from its inception and explained how the project had evolved to meet the technical, economic and planning constraints at the site.

About the Staff

Tony Norton *Head of the Centre*

Tony Norton is the Head of the Centre for Energy and the Environment; he is a Chemical Engineer with a background in the international energy industry. His experience of the economic and commercial issues around energy provision is extensive and includes policy advice to government. Tony's work at the Centre includes the energy aspects of local planning and the development of CHP and heat networks.

Dan Lash *Senior Research Fellow*

Dan studied architecture at the University of Sheffield and now specialises in low energy building design, including natural ventilation, thermal performance, comfort, and maximising natural light. His expertise extends to design reviews, strategic planning and area assessments for energy and emissions. He is also a CIBSE Low Carbon Energy assessor and accredited Passivhaus designer.

Andrew Mitchell *Research Fellow*

Andrew has more than fifteen years' experience in monitoring the environmental performance of buildings. He has evaluated performance against expectations and his results have been used to manage energy consumption and inform future building designs. He also specialises in acoustics, air quality management and transportation. He is a member of the Institute of Acoustics and the Institute of Sound and Communications Engineers.

Andrew Rowson *Research Fellow*

Andrew is an engineering mathematician with a background in construction, engineering and computer modelling. He currently specialises in renewable energy technologies and policy. He was project coordinator for the IEE funded project FOREST which supported biomass heating through the adoption of best practice and deeper supply chain integration.

Matt Eames *EPSRC Research Fellow*

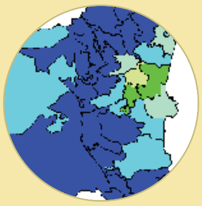
Matt is working on the EPSRC project 'eTherm', which is focused on early stage building models and the prevention of overheating in buildings. His main interests are building model optimisation, estimating the impact of climate change on the built environment and models describing heat stress within buildings. Matt has also worked with CIBSE on the limitations of existing methods for representing extreme weather in the summer.

Mike Wood *PhD student*

Mike has carried out research and consultancy into all aspects of sustainable building. His areas of expertise include acoustics, thermal performance and building monitoring; he is also a member of the Institute of Acoustics. Mike is in the second year of a PhD looking at early stage building models with Matt Eames where he is finding novel ways to shorten the time it takes to model the thermal performance of buildings.

Edward Shorthouse *PhD student*

Edward has a degree in Physics and Philosophy and as a former manager of National Trust properties he gained a professional interest in the built environment and the requirements of building development within heritage and special interest sites. He is currently in the second year of a PhD with Matt Eames looking at overheating in buildings, particularly during extreme weather and future heatwaves.



Carbon Emissions in Teignbridge

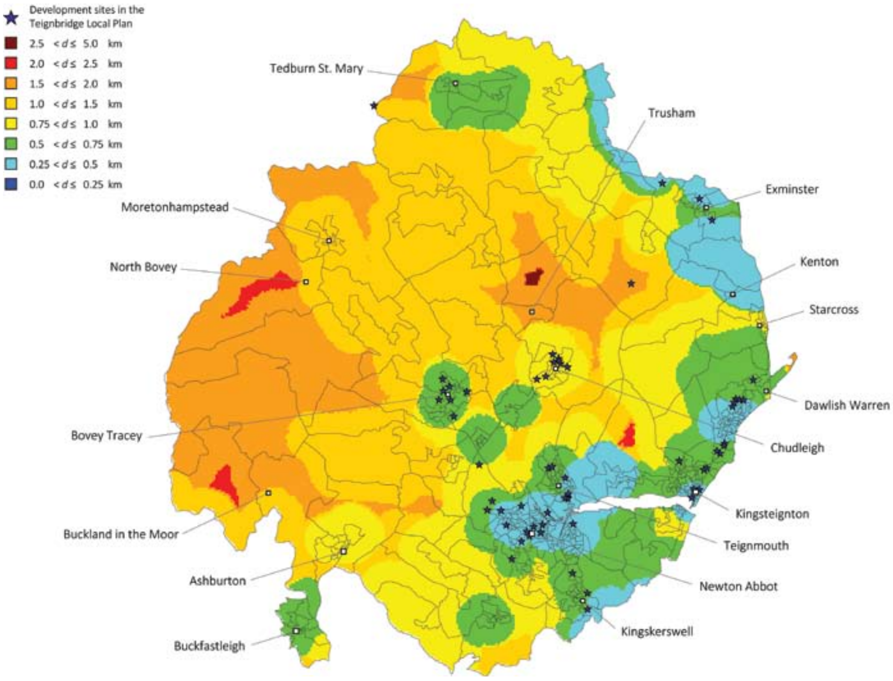
A novel method for calculating additional emissions from new developments has recently been adopted by Teignbridge District Council. Sustainable development will be encouraged through the additional flexibility afforded to developers.

In March 2014 the Government announced the outcome of its Housing Standards Review (HSR) consultation which ran at the end of the summer of 2013. The decision was taken to remove the ability of local planning authorities to set energy standards in excess of the 'zero carbon homes' timetable, which will see all new homes achieve 'zero carbon' from 2016. Meanwhile the Centre has developed a highly novel calculation methodology for new developments in Teignbridge which will enable developers to demonstrate compliance with carbon emissions targets. The extended scope includes emissions captured by Part L of the Building Regulations but also accounts for additional unregulated energy consumption and emissions from transport associated with the development.

Transport emissions were based on a GIS analysis that apportioned carbon emissions to the development based on travel behaviour data taken from the 2011 Census. The potential benefit of incorporating sustainable transport measures can then be assessed.

The new method enables developers to use their judgement to meet emissions reduction targets in a more flexible manner and has enabled Teignbridge District Council to implement their Local Plan and its headline objective of reducing carbon emissions by 42%.

The Centre provided expert evidence in support of the method and associated policy at the Examination in Public and, following its approval by the inspector, worked with the council to develop a spreadsheet tool incorporating the calculation. The tool went live in September 2014 and will provide consistency for developers, giving them a quick and easy method to demonstrate compliance with local policy. It is hoped that the new methodology will help to prioritise sustainable development in Teignbridge.



The image shows the average length of journeys to work from within the Teignbridge district based on the methodology created at the Centre. Typical rural journeys are longer than urban ones and likely to result in higher emissions.

Many new developments however are situated on the outskirts of existing urban areas and while those journeys are likely to be more similar to urban journeys, under a simple analysis they would be classed as rural journeys.

By creating a buffer zone around the areas and searching for minimum journey distances, a more realistic journey profile for the district can be assembled.

Planning for Renewable Energy in Brentwood

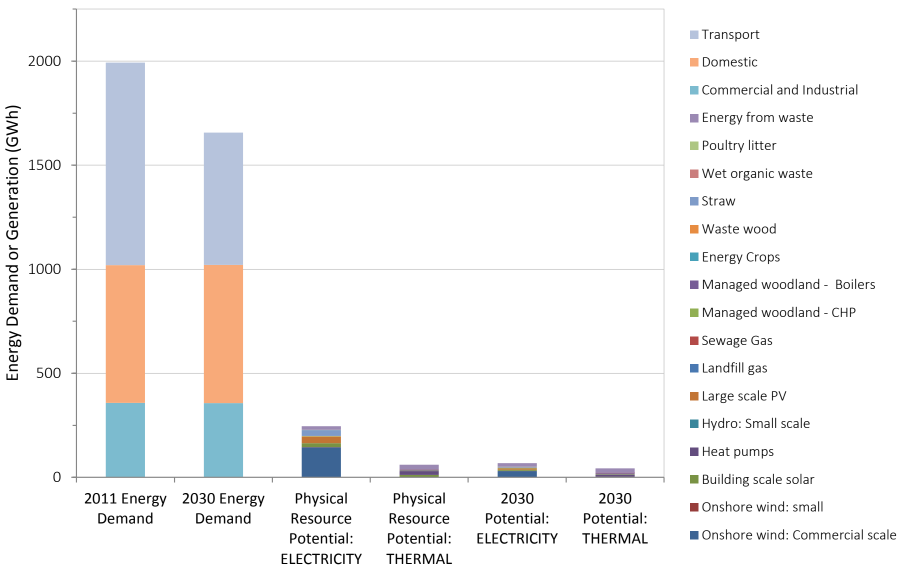
A quantitative assessment of energy demand and renewable energy potential, based on resource availability and technical feasibility, can be a valuable tool when considering local policies to support the development of renewables.

Brentwood Borough Council in Essex commissioned the Centre to undertake a renewable energy capacity study and to recommend the right energy mix for the Borough.

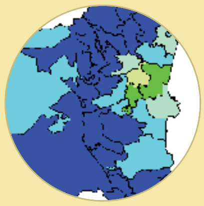
The output of this study would form part of the evidence base for the emerging Local Plan, which sets out planning policy to 2030. Currently around half of all energy used in the Borough is for road transport, with a third consumed in homes and about a fifth in the commercial and industrial sector. While carbon emissions have fallen over the past seven years in line with similar national trends, energy use and carbon emissions may increase by about 10% over the period of the Local Plan if a 'business as usual' trajectory is followed. An analysis of the impact of key Government policies in Brentwood indicates potential for a decrease in energy use of 8% with associated carbon emissions falling by 28%.

Renewable energy capacity in Brentwood was assessed using existing data sources and the Government methodology established by SQW Energy along with an indicative mix of technologies. The resulting scenario would generate about 9% of the energy requirement for the Borough, falling short of an ambition to meet 15% through renewable sources. The technologies considered were classified into three groups: standalone technologies, district schemes and building technologies. Large stand alone technologies have the greatest potential impact, although large scale deployment will need to overcome various barriers including tensions between sustainable development and the need to protect Green Belt land which comprises about 80% of the Borough.

District energy could form a significant component of the Borough's energy mix with promising sites at West Horndon and the Brentwood Enterprise Park at the edge of the M25. In addition to renewable energy capacity, advice was given on setting sustainable construction standards for new developments that may make it more cost effective for developers to consider district energy schemes rather than treating individual buildings in isolation.



The renewable energy potential in Brentwood is some way short of the 15% ambition that has been expressed. Large scale and district energy schemes are seen to have the most potential but various barriers will have to be overcome before they can be adopted.

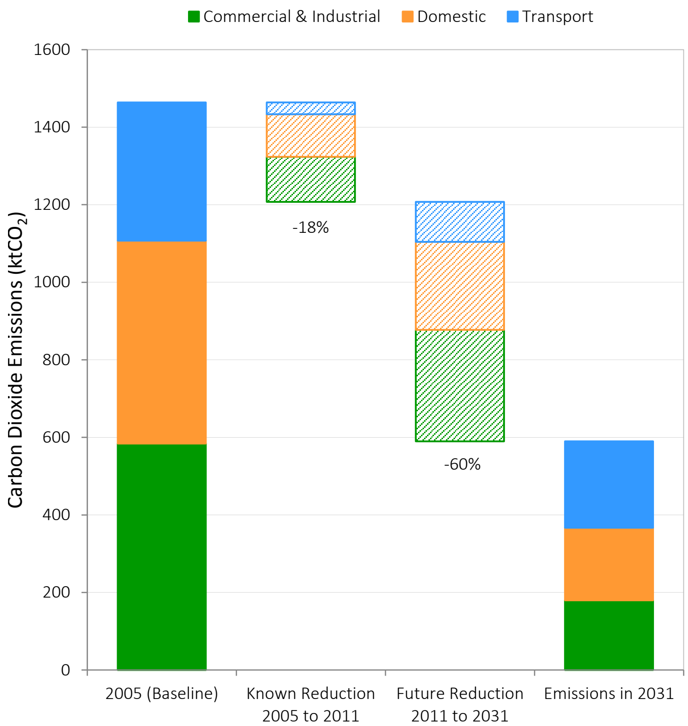


Carbon Reduction Review in Plymouth

The Centre was commissioned by Plymouth City Council to update its previous carbon reduction report from 2011 and to assess the City's progress towards its targets through local and national measures.

The addendum considers the city's progress on carbon reduction and suggests challenging but achievable targets and policies to 2031, which tie in with the emerging 'Plymouth Plan'. Between 2005 and 2011 carbon dioxide emissions decreased by 17.5%, although this trend, observed elsewhere in the South West, is largely attributed to the economic downturn and national policies which have seen a reduction in the carbon intensity of grid electric and the increased fuel efficiency of new vehicles.

The commercial and industrial (C&I) sector is responsible for 39% of the city's carbon dioxide emissions, while the public sector is responsible for 11% and the residential sector 34%. Energy use in homes varies across the city, depending on the size, age, condition and tenure of the property. Transport accounts for 27% of emissions with car availability and commuting much higher in the east of the city where incomes tend to be higher.



Plymouth has made progress on its carbon reduction and may be ahead of other authorities but step changes across all sectors will be required to meet the 2031 targets.

Local conditions and policy were assessed in consultation with council officers and by reference to key documents. While there will be some benefit the vast majority of premises in Plymouth are unaffected by national carbon reduction policies. The main incentives are instead market driven, for example rising energy bills or the desire to improve corporate image.

In the domestic sector Plymouth has been proactive in securing two Energy Company Obligation (ECO) schemes in the city. Associated fabric improvements worth £50 million may put Plymouth ahead of other areas, but the rate of improvement is still too slow to meet national targets. This failure of the Green Deal and ECO as mechanisms to drive carbon reduction can also be seen at a national level through the drastic fall in the rate of installation of efficiency measures.

In the transport sector national policies anticipate increased penetration of fuel efficient vehicles and biofuels, while options for local action include behaviour change towards sustainable travel, infrastructure for electric vehicles and eco-driving training. Plymouth City Council's third Local Transport Plan (LTP3) covers all policies identified at a national level as well as a large number of the local initiatives although there are opportunities to roll out eco-driver training more widely across the city.

The national carbon reduction trajectory indicates that by 2031 emissions in Plymouth may be 47% lower relative to 2005. However, the UK as a whole is not achieving carbon reduction at the required rate and step-changes will be needed across all sectors. Analysis of local conditions indicates that if under-performance at a national level is addressed (through the strengthening of existing policies), it may be possible for Plymouth to achieve an overall reduction of 60% over the same period through increased local measures and deeper penetration of renewable heat.

Sustainable Buildings

Sustainable Building Design

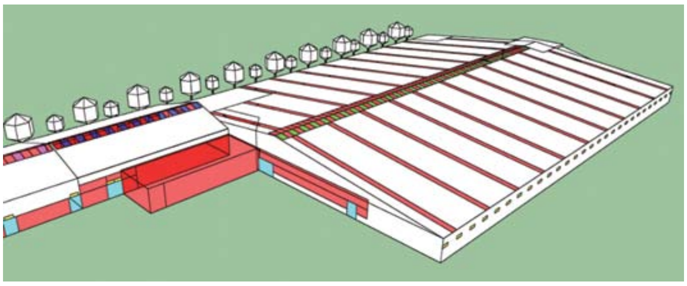
Changes to Part L of the Building Regulations will improve the efficiency and sustainability of new buildings. Technical advice and the latest modelling methods provided by the Centre can help buildings to comply with the new standards.

The Centre continues to be engaged in the design of buildings in the region, through working with clients to set sustainability standards in new buildings, providing renewable energy assessments, investigating the impact of design options on energy and environmental performance, ensuring compliance with regulations and improving in-use performance through the 'Soft Landings' processes.

Projects this year have included Axe Vale Community College, Ladysmith Infants School, Highweek Community Primary School, the new Rushbrook Centre in Totnes and the new Exeter Central Library. Other buildings include care homes, garden centres and an unheated military vehicle storage facility.

One of the most significant changes this year has been the introduction of the new versions of Part L of the Building Regulations. Transitional arrangements will allow work that has commenced on site prior to April 2015 to use the older version of the regulations, but newer projects will be expected to use the new regulations for compliance modelling and the generation of Energy Performance Certificates (EPCs).

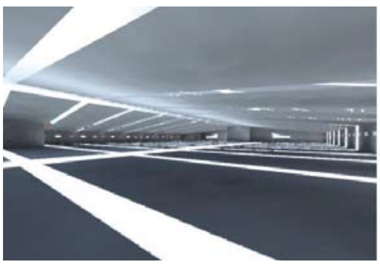
There have also been developments in the standards and analytical methods used to assess environmental performance. This includes the application of new overheating standards from CIBSE, which apply criteria based on the principles of adaptive comfort which reflect the user experience of comfort more closely. Rather than a fixed temperature, a moving target is used which reflects the external temperature. Analysis at the Centre has shown that these standards are still challenging to meet and early consideration of critical design parameters such as orientation, façade, thermal mass and ventilation strategy will remain crucial to avoid problems with overheating.

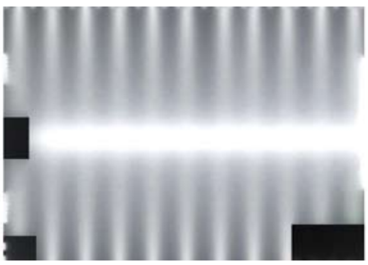


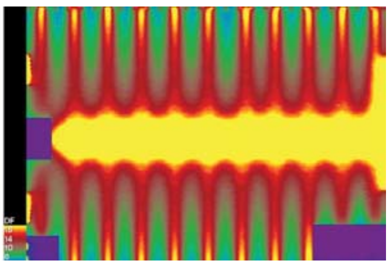
This IES model of a large garden centre was used to develop daylight models of the interior space based on conditions over the whole year.

A further development has been the mainstream adoption of climate-based daylight modelling within commercial building simulation software. Designed spaces can now be modelled over a whole year rather than relying on individual 'snapshots' of worst case scenarios. Rigid adherence to historic standards such as the daylight factor can lead to excessive glare under some conditions, while a lighting strategy that meets required levels for the majority of the time will be less likely to result in increased cost or conflict with other design objectives.

Engagement with the Department for Education indicates that these standards will become more defined as they enter the mainstream. Building modelling, especially in the early stages of design, will therefore continue to be important in the delivery of new buildings.



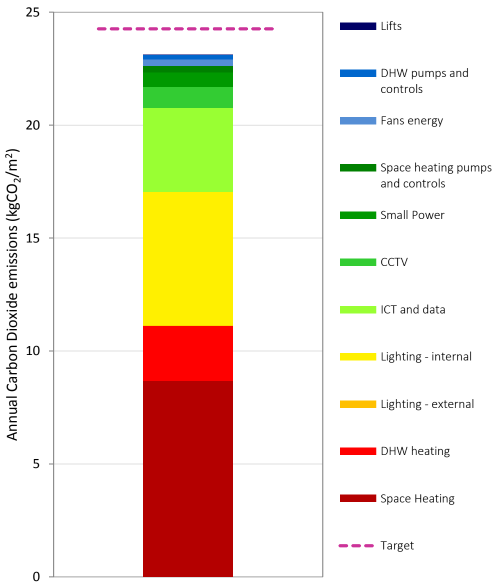




Lighting designs based on daylight factors alone can lead to glare under some conditions. Automatic controls are inexpensive and dimming in daylight hours was estimated to save £14,500 a year.

The 'DEC B' Standard

The Centre has been working with Devon County Council to develop an in-house standard in an attempt to close the performance gap between predicted and actual energy use.



Breakdown of anticipated energy consumption by end use under the DEC B standard.

Standards governing carbon emissions from new developments are set within Part L of the Building Regulations and are strengthened in three-year cycles. In spite of tougher standards, it is commonly accepted that the performance of new buildings in practice is often significantly poorer than predicted at the design stage. It has been estimated from the *CarbonBuzz* project that new buildings typically use 1.5- 2.5 times more energy than was predicted by energy models. Closing this gap is now seen as a priority and CIBSE have brought out guidance to help improve design stage predictions.

The Centre meanwhile has been working with Devon County Council to develop an in-house performance standard for its new schools. The 'DEC B' standard was presented to the DCC Development Committee and the Environment Policy Task Groups and is based on the *Class Space* design by framework contractors NPS Ltd. Estimates of carbon emissions are based on the actual specification and intended use of the building and are being validated through monitoring in the early years of occupation. Analysis of the results will be used to provide feedback into the design of the next tranche of school buildings.

Acoustics Consultancy and Design

Acoustics design and remediation has included design advice for school buildings and assessments of residential exposure to noise from industrial sources.

Noise exposure can hamper learning, communication and sleep so standards are in place to limit ambient noise levels. The Centre has provided guidance on acoustics for primary schools in Broadclyst, Woolacombe and Ide, and at Haven Banks outdoor education centre. At Broadclyst, the new school hall design incorporates ventilation plant and air source heat pumps and analysis of noise propagation to the nearby dwellings identified specific items of plant that could constitute a noise nuisance and would therefore require attenuation.

Noise nuisance was also assessed on behalf of a plastics manufacturer, where a new housing estate is planned close to the factory. The client was keen to ensure that planning conditions on the developer would stipulate adequate noise mitigation measures for the new homes.

At Broadclyst Primary School, external air conditioning units were predicted to be the dominant source of noise disturbance for nearby residents.

Energy Efficiency

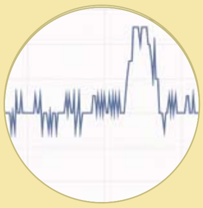
Building Monitoring

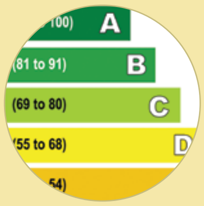
The Centre has extensive site monitoring expertise which continues to offer valuable insights into the potential and actual energy efficiency improvements that can be achieved when a building undergoes refurbishment.

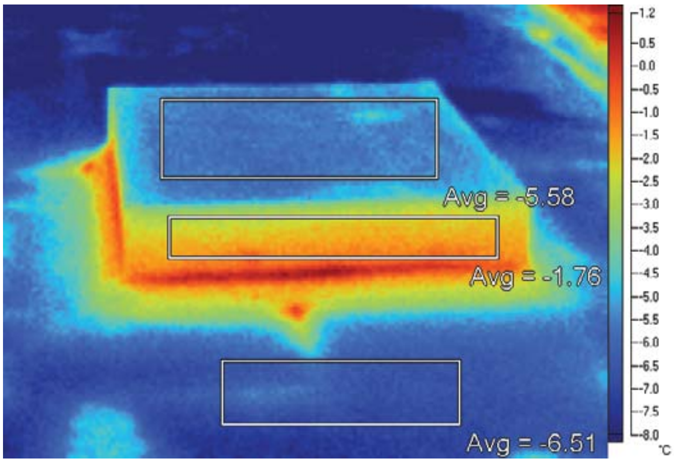
Architects Design Group

The University has an ambitious carbon emissions reduction target of 43% by 2020 relative to a 2005/2006 baseline. To achieve this will require wide-ranging improvements to building fabric, building services and electrical equipment for refrigeration, IT and lighting. The University of Exeter's estate is diverse in terms of its age, form and function, and each building will require a tailored approach to refurbishment. Cornwall House, the Students' Union building, was selected to act as a testbed for a major refurbishment—its modest size creating a manageable but worthwhile project. Works included overcladding the poorly insulated prefabricated concrete external walls and flat roof with external insulation, new heating and ventilation plant, a solar thermal system, new lighting and improved submetering. The Centre contributed to the project at various stages, including procurement, commissioning of the metering systems and comparing energy consumption before and after the refurbishment.

Infra-red images of the structure revealed a substantial improvement in its thermal performance but identified some areas where better detailing could have reduced thermal bridging through the insulation layer which would have improved energy efficiency further. This evidence will be particularly valuable when specifying external installation on similar buildings. Meter data shows that the refurbishment has reduced electricity consumption by about 25% through efficient lighting, automatic lighting controls and demand-controlled ventilation. Gas consumption has fallen by about 43% due to the improved insulation, reduced ventilation rates and closer control of the heating plant.





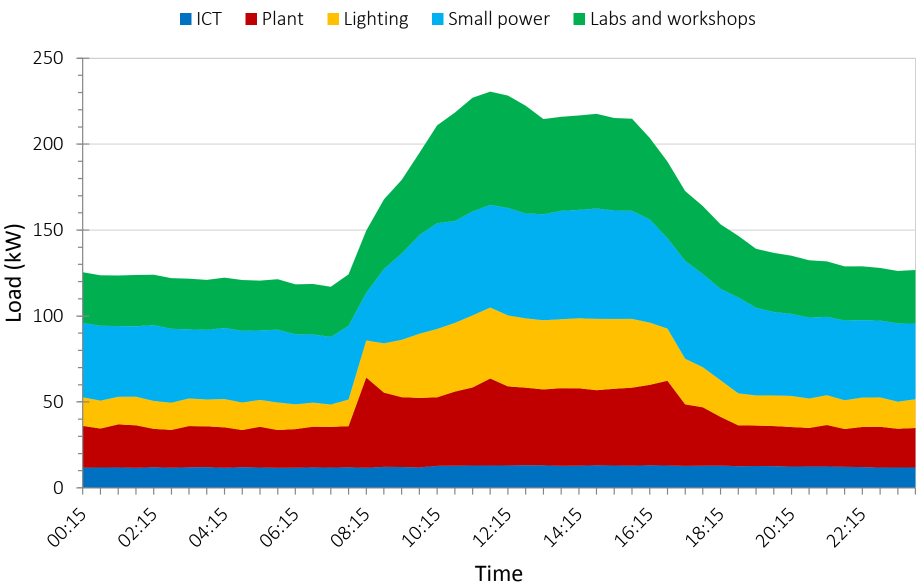


Subsequent thermal imaging at Cornwall House revealed that the standard of insulation was generally good, but there were some weak spots such as these former rooflights.

Architecturally speaking the Harrison Building could be considered to be ahead of its time, unfortunately the same could not be said about its thermal performance or energy efficiency.

In order to achieve the overall carbon target, the energy efficiency of the larger buildings on the campus will also need to be improved. The Centre has therefore been evaluating energy use at the Harrison building, home of the engineering faculty, in some detail. The building itself was constructed in the 1960's and suffers from poor standards of thermal insulation and airtightness, contains a considerable amount of energy intensive machinery, and has an oil fired heating system. The aim of the project was to identify the scope for energy and carbon savings, including the potential to move to a less carbon-intensive fuel source, and to better understand the end uses of energy within the building.

In common with similar building specific projects obtaining appropriate energy data has been challenging. Electrical distribution, for example, is arranged spatially rather than by end use, making it impractical to make direct measurements of total lighting, air conditioning or small power loads. Instead, the thirteen major distribution circuits were monitored, along with samples of representative loads in the building (air conditioning, computer cluster rooms, seminar room lighting and power, offices, and major process loads). Together with bottom-up estimates of consumption, the Centre has been able to produce a detailed energy profile to act as a baseline from which the potential of various improvements can be measured.



Weekday electricity consumption profile for the Harrison building, with estimated breakdown by end use.

Significant baseloads were present in each category of energy use. Overall the baseload is around 54% of the peak load for the building. During the course of the day the various baseloads account for almost 58% of the total daily energy consumption.

The fact that baseloads are 'always on' means that even modest reductions can yield proportionately high energy savings.

Energy Efficiency measures at the RD&E

Previously the Centre helped the Royal Devon and Exeter Hospital to win £1.1m of funding from the Department of Health to improve energy efficiency. Subsequent monitoring across the site has been used to quantify some of the savings.

Key improvements have included a boiler replacement programme for the nurses' residences where old oil boilers have been replaced with modern condensing gas boilers. The new boilers will provide efficiency savings and the carbon savings for switching fuels from oil at 0.29 kg CO_2e/kWh to natural gas at 0.20 kg CO_2e/kWh are also significant. Better controls in individual flats and rooms and the addition of showers as well as baths are expected to enhance savings further.

Reducing losses from the extensive heating network has also been tackled with a range of insulated flange and valve jackets,

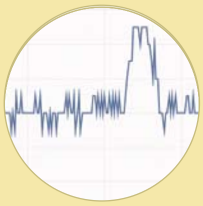
While pipework is generally well insulated, valves and flanges are often neglected. These insulated jackets represent a simple but cost effective way to save energy and improve the working environment.

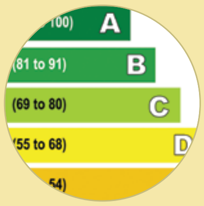
with estimated energy savings in the order of 1,000 MWh a year and payback expected within 12 months. Plant rooms with well insulated pipework also provide an improved working environment and reduce the risk of burns.

The RD&E hosts a regional laundry at Wonford which is one of the most energy intensive spaces on the site, second only to the HSDU (Hospital Sterilisation and Decontamination Unit) which also services health centres in the surrounding area. Centralised services in themselves have the potential to reduce costs through economies of scale and efficiency savings associated with larger, well maintained equipment. Among the measures which have been implemented at the laundry are a switch from fluorescent to LED lighting. Monitoring of the relevant electrical circuits has shown how the lighting load has been reduced by almost 60% from more than 20 kW to about 8 kW. The step changes in the associated graph (below right) show clearly how power consumption has fallen as each phase of the lighting project was completed.

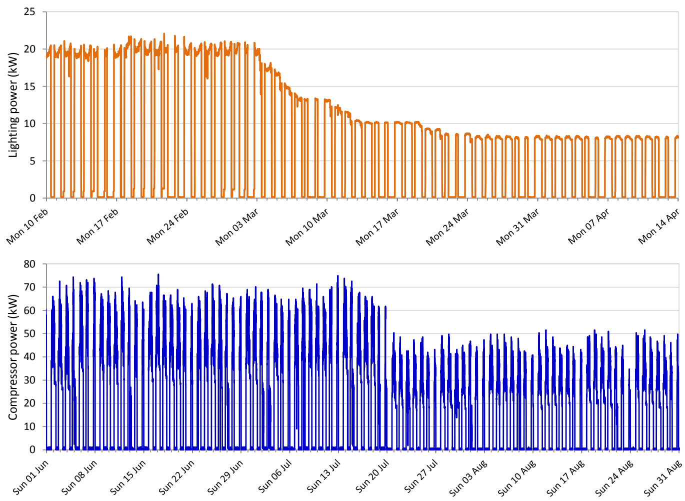
Meanwhile a survey of the compressed air system identified a series of air leaks which would have combined to make the compressors less efficient. These have been addressed and logged data has shown that the daily energy requirement for the main compressor has reduced from 550 kWh per day to 400 kWh. In both cases these savings are consistent and have been sustained, and with the laundry operating seven days a week, the combined savings will be significant.

The use of standalone logging equipment to capture power and temperature data has enabled a timely assessment of the savings that have been achieved but it can also provide insight into occupant behaviour and the way that the buildings are used. For example, overheating in one of the ward kitchens has necessitated the use of a split air conditioner unit. These units can be expensive to run but the costs can be mitigated if they are used only as required. Simple temperature logs indicate that the kitchen is generally used between 06:00 and 22:00 but also



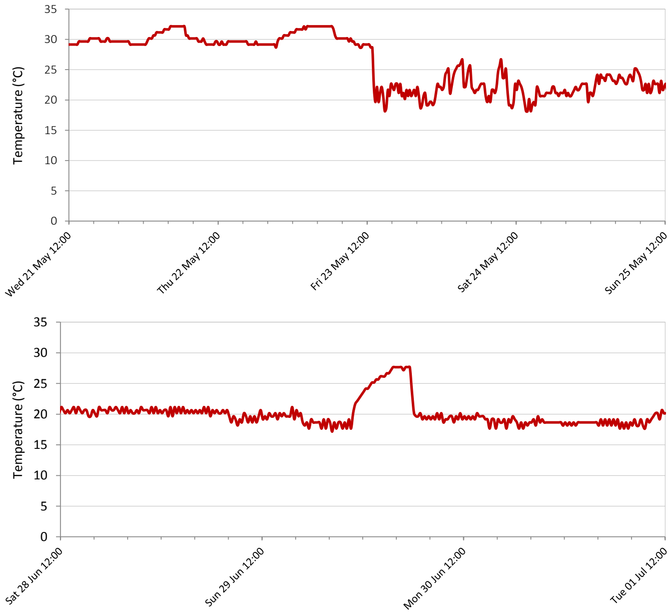


The laundry operates seven days a week and is one of the most intense energy users on the Wonford Site.



The fall in electrical power in the laundry is clearly seen in the graphs above which are based on the logged output from current clamps connected to each of the three phases of the supply.

show how rapidly the temperature is brought down when the unit is switched on (see below). It should therefore be possible to shut the unit down for at least 30% of the time.



Analysis of temperatures in an overheating ward kitchen. After a period of adjustment (top) the temperature settles (bottom) to a comfortable level. Rising overnight temperatures in the top graph where the door is closed indicate when the kitchen is used, while a small hump in the bottom graph after the unit is switched off overnight shows how quickly the temperature can be lowered. The unit could be turned off for up to 30% of the time without affecting working temperatures for users.

In the longer term increased submetering can give much greater resolution in energy data and a better understanding of how and when energy is used. In general the Centre recommends installing additional metering where opportunities arise, as a part of a refurbishment for example, or when infrastructure or equipment is replaced. On large sites or those without adequate network infrastructure, systems that make use of mobile communications through SMS (Short Message Service) can be implemented to supplement fiscal metering. Many energy management systems include software and 'dashboards' to help display and manage data, although in our experience these interfaces can be frustrating to use and users should ensure that the functions provided are suitable. There should always be an option to download complete sets of data in simple text files as these can be easily manipulated in external spreadsheet programs or other software.

Exeter Civic Centre

In the life of a building, there are points in time where far reaching decisions are taken about their future. At the Civic Centre in Exeter plans to replace the 45 year old oil boilers and install a new data centre are such a trigger point.

The City Council commissioned the Centre to undertake a wide-ranging assessment of the Civic Centre buildings and to look at the broader implications of these changes.

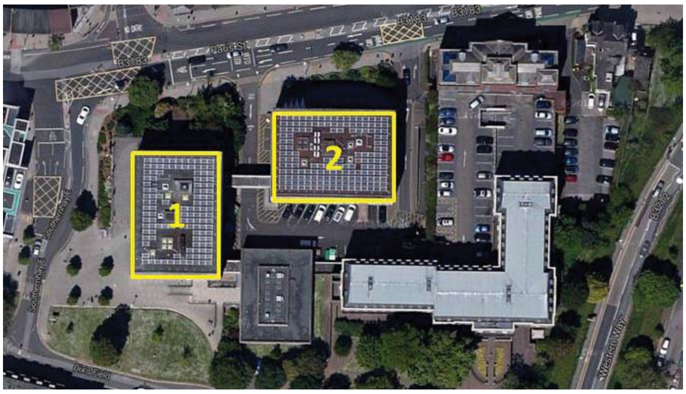
Energy performance at the Civic Centre was found to be better than a 'typical' office building but some way from representing current 'best practice'. The building has benefited from double glazing and a roof mounted PV installation which in its first year generated revenue of about £8,900 from the Feed-in Tariff as well as reducing the bill for imported electricity by about £9,000.

The relocation and expansion of the data centre is being planned at the same time as the boiler replacement. It will allow the sharing of IT provision with neighbouring districts and should provide overall efficiency savings. At the Civic Centre however the electricity consumption for IT could be more than doubled as a result. The changes will need to be mitigated by making good use of free cooling and the re-use of waste heat which could contribute to the heating requirements of the building.

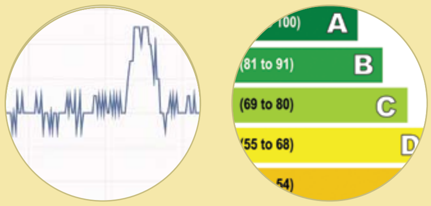
The existing boiler plant consists of two 1.2MW oil boilers and is considerably oversized for the current load. It is estimated that the peak heat load is around one quarter of the original boiler design capacity and two thirds of the peak capacity of a single boiler. In addition the heating system provides space heating only, so the boilers are switched off in the summer months.

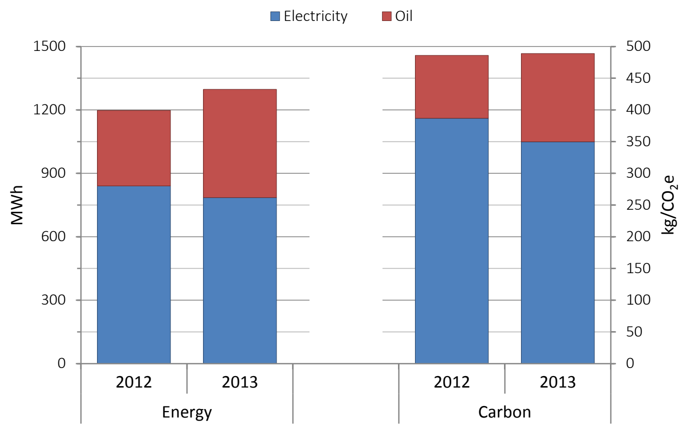
Running for long periods at low capacity has an adverse effect on the boiler efficiency and leads to unnecessarily high fuel bills. The combination of low heat requirements and limited operating hours means that potential replacement systems such as biomass, which have higher capital costs, are unlikely to be economically attractive.

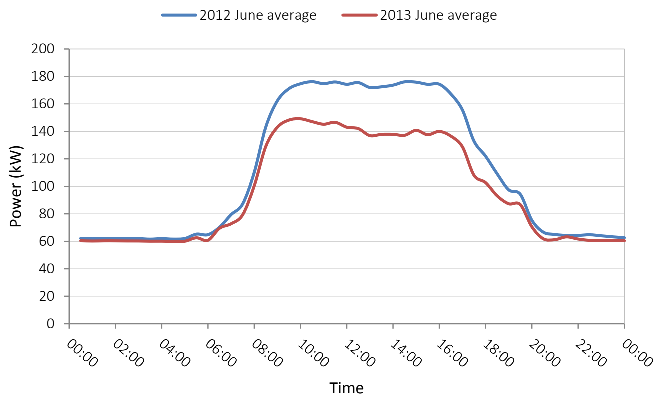
Anecdotal evidence from staff also indicated that areas of the building were either too hot or too cold and this prompted the installation of 60 standalone temperature sensors across the site. Monitoring over a period of two months showed that the building can be very effective at storing heat and that internal temperatures are generally high but can vary considerably from one side of the building to the other, particularly in Phase 1. This has been partially attributed to solar gain but is also likely to be a result of changes to the internal structure which have not been reflected in the heat



Plan view of Phase 1 and Phase 2 Buildings. Temperature differences due to solar gains were more prevalent to the south and east, particularly above the second floor.





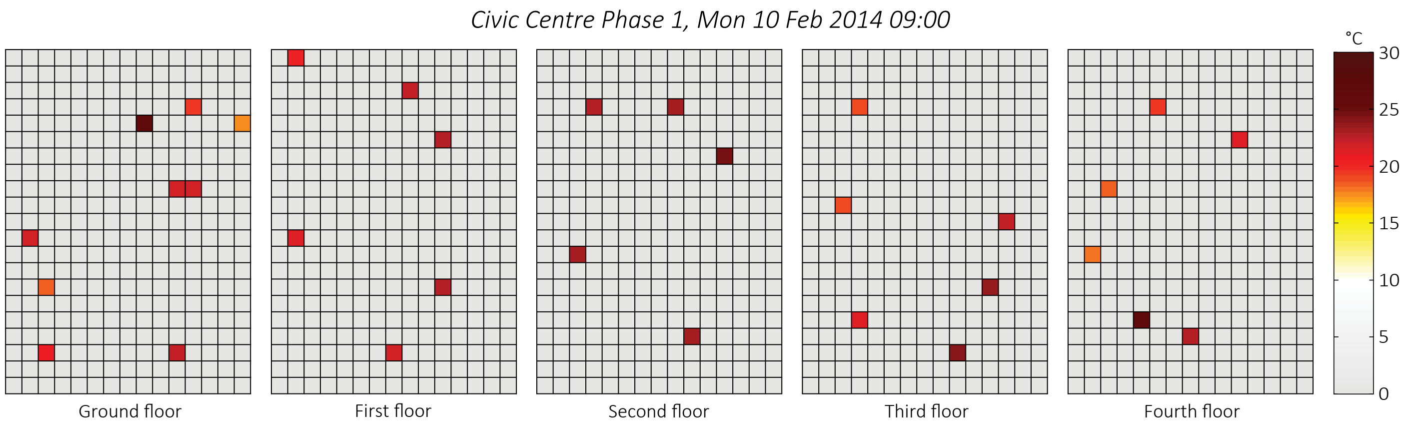


The overall rise in imported energy at the Civic Centre between 2012 and 2013 is around 8% (above left) but is largely a result of the cold winter. Extending the heating season into May 2013 consumed an additional 2,250 litres of oil. The installation of 70 kW_p of PV in February 2013 meant that imported electricity was reduced by almost 7% in 2013, with the peak load in June reduced by an average of 34 W between 10:00 and 16:00 (above right). As a result overall carbon emissions have remained broadly unchanged.

distribution system or the sensors which drive the heating and building management system (BMS). A new system should address excessive temperature gradients across the building with more or better sensors and improved control through the BMS.

Plans to develop a district heating network in Exeter City Centre are another important consideration. In 3 to 5 years' time it may be possible to connect to a heat network with the prospect of low carbon heat at a competitive price. The space in the Civic Centre plant room that would be freed up by removing the oil heating system would also create an opportunity to deploy CHP units at the site with the possibility of exporting heat and electricity while also serving its own needs. A CHP system could make use of the existing flue which runs through the centre of the Phase 1 Building and could be important when considering the viability of such a scheme.

After extensive analysis the most pragmatic solution was centred on the installation of condensing gas boilers, with options for utilising waste heat from the new data centre. To avoid the new boilers becoming a 'stranded investment', provision for connection to the district heating network was recommended to allow the new system to play an active role, utilising its excess capacity to feed into the network with the possibility of adding CHP later.



Approximately sixty temperature sensors were placed around the Phase 1 and Phase 2 Buildings and temperatures recorded over a period of two months. The image above shows unevenness in the distribution of temperatures, as early as 09:00 on a Monday morning there are early signs of overheating to the south and east of the building.

Renewable Energy

District Heating and CHP in Exeter

Considerable progress was made last year in establishing the feasibility of district heating and CHP in Exeter with a successful application to the Heat Networks Delivery Unit (HNDU) at the Department of Energy and Climate Change.

HNDU has been set up to provide grant funding and guidance to local authorities to progress the development stages of heat network projects. The Unit comprises technical and commercial experts who evaluate applications to the fund and provide guidance to successful local authorities.

The award of £284,000 is for the development of a public sector energy services company in Devon and project partners are all SWEEG members:

- Devon County Council
- East Devon District Council
- Exeter City Council
- Teignbridge District Council
- Royal Devon and Exeter Hospital
- University of Exeter

Successful bids to HNDU must provide evidence of good quality work prior to the application to demonstrate the feasibility and value of progressing the heat network projects. Local authorities are also expected to provide evidence of the capacity to fund and manage the project, including political and senior management support. Wider benefits must also be highlighted including carbon reduction and reduced costs to consumers.

In Exeter the funding is being used to commission technical, financial and legal consultants to develop the business case and procurement process for engaging a private sector partner to develop two district heating and CHP schemes in Exeter. Initial networks are planned for the South West Exeter urban extension where new build homes and businesses will have access to heat from the new Marsh Barton Energy from Waste (EfW) plant. A second network to serve the city centre could be based on a new energy centre located at the Wonford site of the Royal Devon and Exeter Hospital and be connected to the City Centre via the University of Exeter's St. Luke's campus.

The project will be structured to enable partners to invest in other energy related projects across Devon.

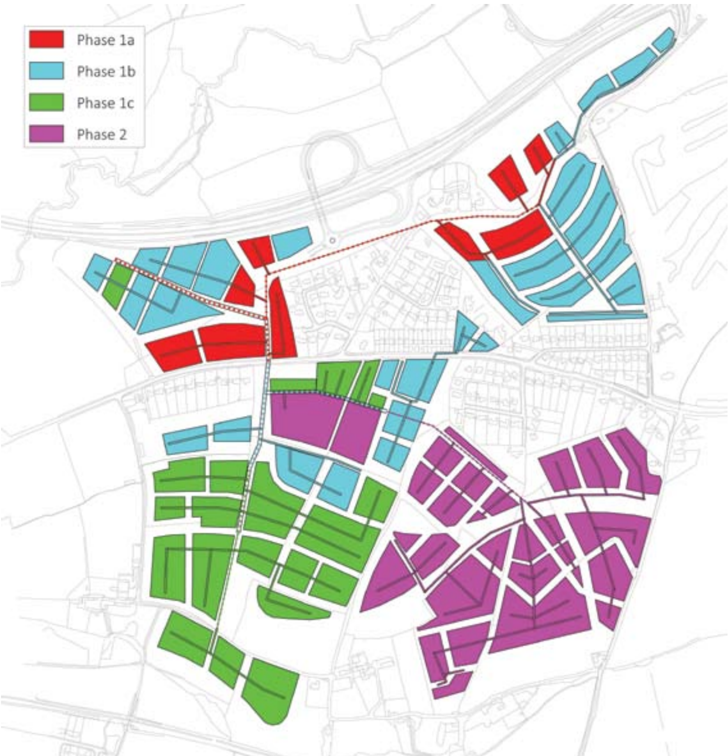
Previous work carried out by the Centre indicates that the South West Exeter development (above right) will eventually require 18,000 MWh of heat and that heat from the EfW plant at Marsh Barton (above left) could provide this through a district heating network with a CO_2 saving of 3,500 tonnes per annum. This represents an 80% saving over individual heating systems using natural gas.

District Heating and Energy from Waste in Tiverton

District heating is a viable solution to the zero carbon requirement for new developments after 2016. The Centre has now shown that waste from Mid Devon is sufficient to provide heat and power to the new Tiverton East urban extension.

The development plans include 1,520 new homes, a new primary school, a neighbourhood centre and 35,000m^2 of employment space. The study formed part of the evidence base for the Devon Waste Plan which supports the provision of strategic facilities at urban centres, particularly where there is an opportunity for the efficient use of heat and power.

Energy from Waste (EfW) was considered through two thermal treatment scenarios; a traditional rotating kiln, similar to that at Marsh Barton in Exeter, and an Advanced Conversion Technology (ACT) plant. Both are able to operate in CHP mode, providing heat and power to the development, although gas is provided for peak loads and backup. Heat is transmitted through a network consisting of underground hot water pipes, while electricity is fed directly into the national grid. Individual buildings contain a heat interface unit (HIU) which delivers and records the heat drawn from the network. The HIU looks like a gas combi boiler, providing individual control, but it also confers a number of advantages; there is no requirement for flues, maintenance is easier and meter reading can be carried out remotely. Capital and whole lifecycle costs can also be cheaper with the reduced requirement for a gas distribution network and the fact that centralised plant can operate at higher efficiencies.



The phased approach to development in the Tiverton East Masterplan was mirrored in the GIS modelling of the heat network.

The analysis has shown that the residual waste in Mid Devon is around 28,000 tonnes per annum which is only about half of that required to fuel the traditional EfW scheme. The ACT plant allows the heat load to be matched to the development so that 16,000 tonnes of waste are required annually (although the gasification technology considered in this study would require a prepared fuel).

In terms of fuel supply ACT is more efficient than traditional EfW leading to greater resource efficiency and it also attracts higher levels of support through renewable energy incentives. The estimated capital cost of both schemes is substantial; ACT costs £29m and traditional EfW around £66m, although ACT has the added advantage that capital costs can be phased over the build programme. Overall the study shows that ACT provides higher rates of return than traditional rotating kiln technology at the same gate fee and provides sufficient renewable heat and electricity to achieve zero carbon status using a reasonable set of assumptions. Developers can be offered low carbon, site-wide heat at a realistic connection charge and consumers can receive heat at competitive prices compared to individual heating with a gas boiler.

Waste

The Devon Waste Plan

For the past three years the Centre has provided technical input to the Devon County Council Waste Core Strategy, now the Devon Waste Plan, which culminated with its submission to the Secretary of State in April 2014.

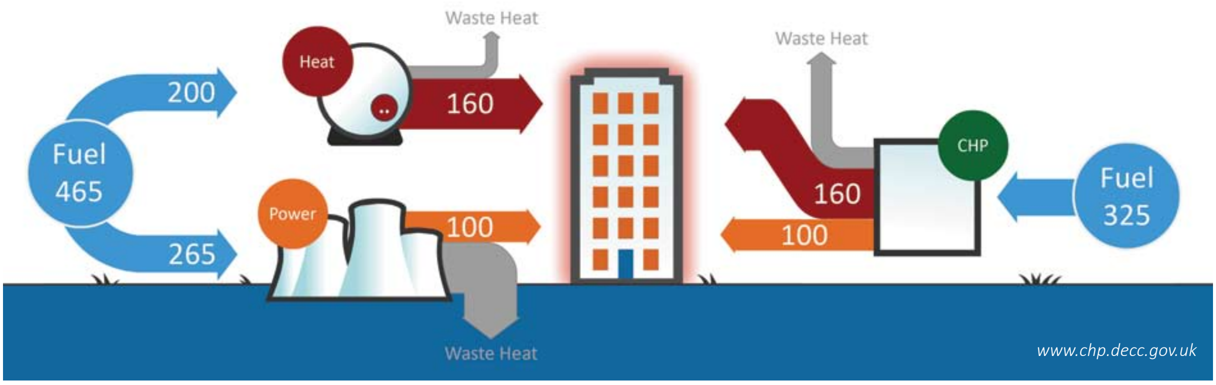
The aim of the plan is to establish the principles and policy direction for waste planning in Devon to 2031 and identify potential strategic sites for waste management activities across the County. A public examination of the plan was held at County Hall in July and the plan is expected to be adopted by the end of 2014, subject to modifications by the Inspector.

Work at the Centre has recommended opportunities for energy recovery from residual waste including anaerobic digestion and thermal treatment. Recycling rates for Local Authority Collected Waste (LACW) in Devon have increased from 33% in 2004/05 to 55% in 2012/13 but this still leaves a considerable amount which would otherwise go to landfill. A key consideration of the Waste Plan has been the selection of sites where the energy generated can be used most effectively, this includes making good use of surplus heat. Energy from waste plants which generate electricity alone generally achieve low conversion efficiencies (typically 20-25%). By contrast sites which enable the development of district heating through Combined Heat and Power (CHP) can reach up to 70% efficiency (see below).

Traditional EfW based on incinerator technology is typically viable at a large scale so finding appropriately sized heat loads can be problematic unless there are industrial consumers nearby. Newer technologies based on Advanced Conversion Technologies (ACT) such as gasification or pyrolysis have better environmental performance and can be viable at a smaller scale so are well suited to provide heat for local district heating schemes in the 1,000 to 5,000 home range typical in new build urban extensions.

A number of ACT plants are operating in the UK and although the technology is yet to be fully proven commercially, the variety of competing technologies suggests that confidence in ACT is growing. Government is keen to develop CHP and is supporting ACT through the £2.8m Energy Technologies Institute (ETI) gasification program which will see one of three shortlisted designs built as a demonstrator plant and run for three years before switching to operation as a commercial venture. Incentive payments for renewable CHP that reward both heat and electricity will provide additional encouragement to the industry.

ACT is now seen as a serious contender for the development of energy recovery facilities and local CHP applications and should be considered as part of an integrated approach to waste management and the efficient provision of low carbon heat and electricity.



CHP offers better overall efficiency than generating heat and power separately. The above figure assumes that power is generated at an efficiency of 38%, in line with average grid efficiency, while boiler efficiency is assumed to be 80%. CHP by contrast provides heat and power at a combined efficiency of around 70%, an increase in fuel efficiency of 30%.

Recycling Plastics in Cornwall

The Centre carried out an analysis on the relative carbon benefits of different waste treatment options for mixed plastics in Cornwall. Early reservations about additional emissions from transport were shown to be unfounded.

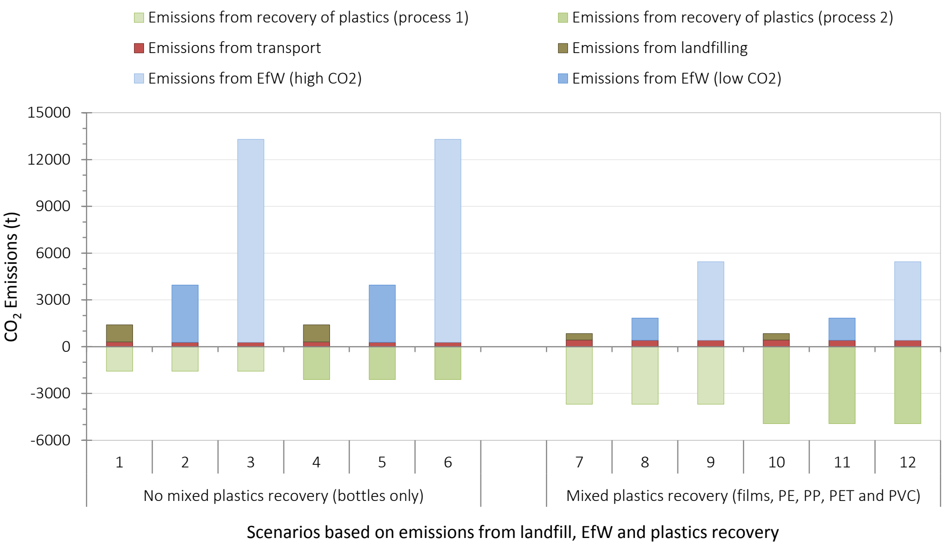
The Cornwall Energy Recovery Centre (CERC) which is currently under construction near St. Dennis is expected to generate 16.6 MW of electricity and will divert 90% of the county's residual waste away from landfill. A proposal for the separation and treatment of mixed plastics is being considered which could provide an opportunity to re-align recycling, collection and complementary treatment processes.

Plastic bottles, largely PET and HDPE (high-density polyethylene) are now widely recycled, although plastic pots, tubs and trays (PPT) and films are seen as more problematic. Among the concerns there was a perception that the carbon benefit of recycling these mixed plastics could be outweighed or adversely impacted by additional transportation to specialist facilities.

Drawing on process data from the WRAP report 'LCA of Management Options for Mixed Waste Plastics' and details of the composition of waste streams in Cornwall, the Centre developed a model which calculated the carbon footprint for a number of recycling options in Cornwall.

The CEE analysis included 12 scenarios for dealing with the residual waste. Landfill and incineration at EfW facilities with low and high emissions were considered, using two different processes, both with and without the separation of mixed plastic waste. Emissions savings from recycling mixed plastics were shown to be between 5 and 12 times greater than transport related emissions. What is also apparent is the positive effect on emissions from the EfW plant of removing plastics. Even under a high CO_2 EfW scenario, the carbon benefits of recycling are sufficient to all but neutralise the adverse effects.

Clews Recycling Ltd.



A range of scenarios were considered reflecting industry practice.

The first set of scenarios (1-6) do not recover mixed plastics and show a net increase in emissions.

Under the second set of scenarios (7-12) plastics are separated and recovered resulting in emissions reduction across the board and net positive emissions in all but one case.

The emissions associated with transport (in red) can be seen to form a relatively small proportion of the total.

Research and Knowledge Transfer

EPSRC Fellowship

As part of the EPSRC funded 'eTherm' research project, the Centre has been researching radical new methods for decreasing the time it takes to perform computer simulations of energy use in buildings.

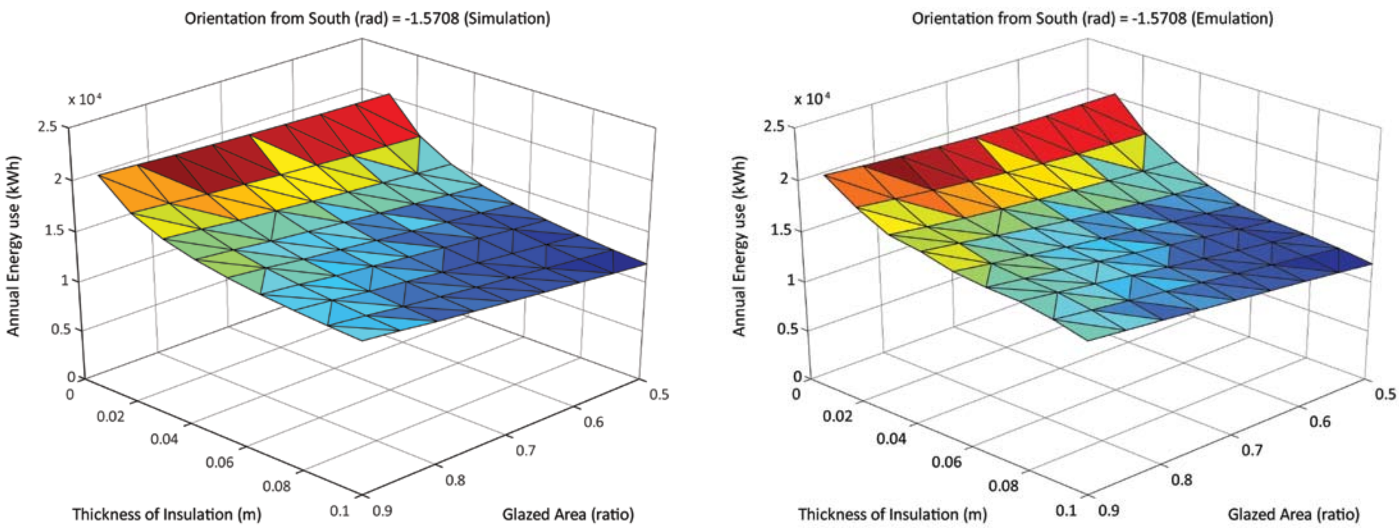
Current methods for modelling energy use in buildings involve complex computer models which simulate heat transfer, solar gains, ventilation and other key building performance parameters. Typically these models fall into one of three methods: conduction transfer functions, state space models and finite difference solutions.

A building simulation can take anywhere from 60 seconds to more than two hours to complete depending on its complexity and in the process will generate a huge amount of data. Most building designers however use just a few performance metrics to judge the efficiency of their designs and much of the data produced by the model can be irrelevant.

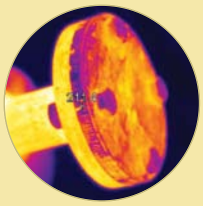
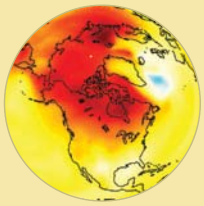
The time taken to run a single simulation is usually manageable within the constraints of a commercial project, but typically only one building configuration can be modelled at a time. If other design options are to be considered, the simulator would need to be set up again and re-run for each new combination of parameters. Due to the complexity and the length of time that it takes to set up and run a building simulation, energy optimisation in the commercial design environment is largely a trial-and-error process. Furthermore, the number of parameters involved means that very few building designs are evaluated completely.

The eTherm project is finding ways to simplify the modelling process and reduce the time it takes to run a building simulation. Eventually it is hoped that this will give designers rapid feedback on the impact of changes to the design or fabric of their buildings and encourage a more methodical way of working when it comes to analysing energy performance.

In order to speed up the modelling without affecting the accuracy of the results, eTherm is using a machine learning technique called Gaussian Process (GP) emulation. The GP emulation process takes the results of a small sample of simulated points



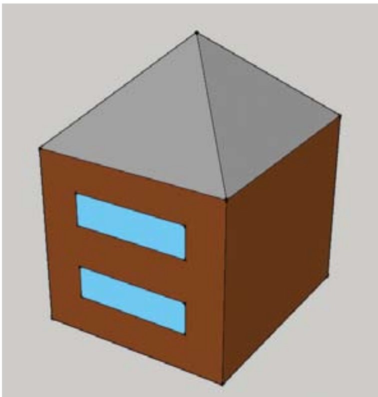
A new method based on emulation rather than simulation can produce similar results in a fraction of the time. The simulator (left) took 17 hours to produce this surface while the emulator (right) required just 30 minutes, including the training period.

and makes an 'educated guess' at the intermediate outputs. The approach is similar to regression analysis but with two important (and powerful) differences:

- For points where the simulator has been run, the output of the emulator will be the same (this is not the case for standard regression methods).
- Where the emulator 'guesses' an output it provides confidence bounds in the form of a probability distribution so that the likelihood of the output being correct can be assessed or compared with other results.

Our first building 'emulator' takes a simplified building (see below) and allows the glazed area, orientation and insulation thickness to be varied. It then evaluates the annual energy use for all of the possible permutations.

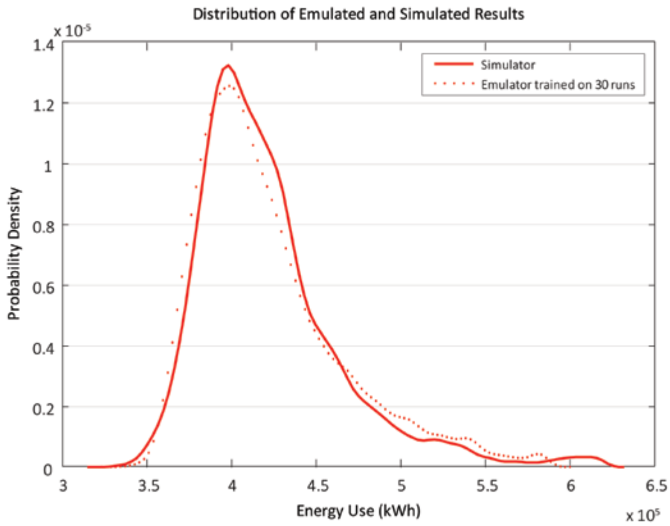


A highly simplified building model has been used to test the performance of the emulator with encouraging results.

Undertaking such an analysis with traditional simulation methods and evaluating each parameter over 10 different levels, would require 1,000 simulations and take approximately 17 hours. Using the GP emulation approach, only 30 simulations are required to 'train' the emulator and the overall analysis takes less than 30 minutes. Agreement between the two methods is very good as can be seen in the surfaces created (see left).

The emulation technique has also shown potential for reducing computation times in other problems where complexity arises from uncertainty or multiple coupled systems. For example, the difference between modelled energy in buildings and the actual performance in use has been highlighted in research and is referred to as the 'performance gap'. Uncertainty arises in the number of parameters that are modelled and the range of values that they can take, many of these are subject to natural variation, for instance due to the weather or from occupant behaviour. Other variables are closely linked or coupled so that parameters such as heating efficiency, the glazed area and air permeability of the building envelope can all affect the building response in ways that are difficult to predict.

A standard method for analysing uncertainty is the Monte Carlo Uncertainty Analysis (MCUA) which can test many thousands of combinations of inputs to determine their effect on the output which is usually in the form of a probability distribution. Our research has focused on using the emulator, rather than the simulator for the MCUA, which can drastically reduce the time taken to carry out this kind of analysis. The figure below compares the results of an uncertainty analysis carried out using the simulator to those of the emulator. The simulator analysis took 12 days to complete whereas the emulator took only 30 minutes (including time for training).



The emulator has been used to reduce the time taken to perform Monte Carlo Uncertainty Analyses. The dotted line shows how close the emulator was able to get to the simulated output but in a small fraction of the time.

The time advantage of testing using the GP emulation method in more complex buildings will improve our understanding of model behaviour under a range of variable inputs and will hopefully lead to new findings that can be used to improve the design of buildings in the real world.

Publications

Details of documents produced by the Centre this year are shown below.
SWEEG members can download documents from www.exeter.ac.uk/cee/sweeg

Scientist's Reports

Number	Title	Author(s)
147	Analysis of Carbon Targets for Plymouth County Council: 2013	D Lash & ADS Norton
148	The Potential for a Zero Carbon Retrofit of the Harrison Building	D Lash & J Rive

Briefing Papers

Number	Title	Author(s)
105	Advanced Conversion Technologies for the Thermal Treatment of Waste - the Current Situation in the UK	AT Rowson & ADS Norton
106	The Use of Site Wide Energy Systems in Masterplanning New Developments	ADS Norton

Internal Documents

Number	Title	Author(s)
868	Barnstaple Roundswell Area. An Initial Feasibility Assessment of Site Wide District Heating and Combined Heat and Power	ADS Norton
869	Investigations of Natural and Artificial Lighting at Air Control Industries, Axminster	D Lash
870	Tiverton Urban Extension, Masterplan Stage Feasibility Assessment of Site Wide District Heating and Combined Heat and Power	ADS Norton & TA Mitchell
871	Thermal Imaging Survey of Cornwall House and Kay House	TA Mitchell
872	Design Stage Part L Modelling of Sidmouth College	D Lash
873	Reconciliation Checks on Historic Data for the University of Exeter's Substation and Building Level Electricity	TA Mitchell
874	Acoustic Assessment of a Proposed Extension to Ide Primary School	TA Mitchell
875	Acoustic Assessment of a Proposed Extension to Woolacombe Primary School	TA Mitchell
876	Design Stage Part L modelling of New Sports Hall at Peter Marland School	D Lash
877	Reconciliation Checks on Historic Data for the University of Exeter's Gas Metering	TA Mitchell

878	Reconciliation Checks on Historic Data for the University of Exeter's Electricity Metering at St. Lukes and Off-Campus Locations	TA Mitchell
879	Reconciliation Checks on Historic Data for the University of Exeter's Gas Metering at St. Lukes and Off-Campus Locations	TA Mitchell
880	Reconciliation Checks on Historic Data for the University of Exeter's Water Metering	TA Mitchell
881	Reducing Energy Consumption and Carbon Dioxide Emissions at the Royal Devon and Exeter Wonford Site	ADS Norton, D Lash, AT Rowson & TA Mitchell
882	An Initial Report on Electrical Loads at Exeter City Council's Data Centre	TA Mitchell
883	Exeter Civic Centre Energy Review	AT Rowson, TA Mitchell & ADS Norton
884	'As Built' Stage Part L and EPC Modelling of Axe Vale Classroom Block	D Lash
885	Acoustics and Ventilation Assessments of a Proposed Teaching Space at Haven Banks Outdoor Education Centre	TA Mitchell
886	Operation and Maintenance Manual for Profile Data for the University's Team Energy Management Software	TA Mitchell
887	'As Built' Stage Part L modelling of New Sports Hall at Peter Marland	D Lash
888	Updated Performance Figures for Montgomery Primary School	TA Mitchell

Journal Publications

Title	Journal	Author
Robust Rainwater Harvesting: Probabilistic Tank Sizing for Climate Change Adaptation	Journal of Water and Climate Change May 2014. DOI: 10.2166/wcc.2014.080	D Lash, S Ward, T Kershaw, D Butler & M Eames
Proof and Concept for the Bayesian Analysis of Computer Code Output for Building Energy Modelling	Proceedings of the Building Simulation and Optimisation Conference 2014, paper ID 10	M Wood, M Eames & P Challenor
A Probabilistic Approach to Estimating the Savings from Voltage Reduction	Proceedings of the Building Simulation and Optimisation Conference 2014, paper ID 104.	M Wood & M Eames

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Published November 2014