ICE PROJECT DELIVERABLE T3.3.1

AN OPTIMIZED SMART ENERGY SYSTEM

DECEMBER 2021

ICE DELIVERABLE T3.3.1:

An optimized smart energy system

About ICE

Supported by the Interreg VA France (Channel) England programme, the Intelligent Community Energy (ICE) project aims to further develop understanding as well as apply innovative and intelligent energy solutions for isolated areas in the Channel region. The surrounding islands and territories are confronted with specific energy challenges. Many islands are not connected to the European electricity grid and rely on imported fossil fuels, notably fuel-powered heat generators. The energy solutions they use tend to be less reliable, more costly and emit higher levels of greenhouse gases than the European continental grid.

In response to these issues, the ICE project considers the entire energy cycle, from production through to consumption, and integrates mature or new technologies so as to develop innovative energy solutions. These solutions will be trialled and tested on two pilot demonstration sites (the Island of Ushant and the University of East Anglia Campus), to prove their feasibility and to develop a general methodology which can be replicated on other isolated territories elsewhere. To transfer this methodology to other isolated territories, ICE is proposing a low-carbon commercial transition offer. This will include a complete assessment of resources and local energy conditions, a proposed bespoke energy transition model and a body of low-carbon skills and technologies available in a consortium of selected businesses. This ICE-certified consortium will promote the offer to other isolated territories both within and outside of the Channel region (initially 5 territories). The ICE partnership model brings together researchers and bodies providing support to SMEs and will be made up of members from both France and the UK in terms of skills, technological and commercial development.

The involvement of local and European SMEs will further boost competitivity and transnational cooperation.

ICE Deliverable T3.3.1 REPORT

An Optimized Smart Energy System

Authors:

Xin Li [a]

Phedeas Stephanides [a]

Guillermo De Loureiro Pereira [a]

Alexis Ioannidis [a]

Arijit Bhattacharya [a]

Antonios Karatzas [a]

Dimitris Zissis [a]

Gwendal Vonk [b]

Peter Connor [c]

Konstantinos Chalvatzis[a]

[a] Norwich Business School, University of East Anglia, Norwich, NR4 7TJ, UK

[b] Syndicat Départemental d'Énergie et d'Équipement du Finistère (SDEF), 9 All. Sully, 29000 Quimper, France

[c] University of Exeter, Penryn Campus, Treliever Road, Penryn, Cornwall, TR10 9FE, UK

Corresponding Author:

Professor Konstantinos J. Chalvatzis

Norwich Business School, University of East Anglia, Norwich, NR4 7TJ, UK

Email: k.chalvatzis@uea.ac.uk

Tel.: +44 (0)1603 59 7241

Suggested Citation:

Li, X., Stephanides, P., Pereira, G. I., Ioannidis, A., Bhattacharya, A., Karatzas, A., Zissis, D., Vonk, G., Connor, P., Chalvatzis, K. 2021. An Optimised Smart Energy System. (ICE report T 3.3.1), Intelligent Community Energy. . https://www.ice-interreg.eu/public-deliverables

Table of Contents

1 Introduction

The University of East Anglia (UEA) has a long history of fighting climate change. From the perspective of academic research, the Climatic Research Unit and the Tyndall Centre for Climate Change Research are world-leading research centres on climate change studies. These research units contribute to the understanding of global climate system and its implications for society since 1972. The Climate Research Unit is famous for constructing a global record of surface air temperatures. In addition, researchers at the Tyndall Centre for Climate Change Research have made significant contributions to climate policy making in the UK as well as the IPCC reports. On the other hand, the University has committed to a low-carbon energy transition on campus. For example, the Enterprise Centre Building is an exemplar of low carbon construction solution, with natural and recycled materials sourced from local supply chain where possible. 30% of its electricity consumption is supplied by solar PVs. The Centre also has a focus to strongly support the development of low-carbon and sustainable businesses.

In 2021, the Vice Chancellor announced that the University will reach net zero carbon emissions by 2045. Using a 'Town and Gown' methodology[1], the remaining carbon budget for the UEA is calculated at 147kT CO_2. Four-fifths of the total emissions are related to energy consumption at its academic and dormitory buildings. The remaining are contributed by transportation related emissions.

Since early 2000s, UEA has implemented a series of measures in order to reduce its carbon emissions. Deliverable 3.3.1 aims to introduce the existing low carbon technologies and their integrated operation at UEA campus, which can provide lessons to the energy transition at Ushant. In particular, it focuses on the demonstration of a smart heating system that has the potential to become a significant source of demand flexibility in the future.

Apart from this introduction, this deliverable has four main sections:

- Section 2 introduces the low carbon technologies adopted at the University of East Anglia, including the solar PV system, the combine heat and power (CHP) plants, the energy efficient gas boilers, thermal heat storage system, and other smart and low carbon technologies.
- Section 3 focuses on the integration of low carbon technologies at UEA in order to optimise the operation of the system and examines the technology options for future energy supply at UEA.
- Section 4 centres on the implementation of low carbon measures from the demand-side at UEA. Two key low carbon technologies and services are introduced, including the smart heating system and the frequency control services. These technologies and services are considered as complementary to the optimisation of the UEA energy supply system.
- Section 5 discusses the potential opportunity for mutual learning between UEA and Ushant.
- Section 6 concludes the deliverable.

[1] 'Town and Gown' methodology calculates the carbon emissions of organisations based on the proportional distribution of its emission levels corresponding to a city's energy related emissions. For the UEA, it represents 4% of the energy-related CO_2 emissions in Norwich.

2 Low Carbon Energy Enabling Technologies at UEA

As an integral part of its existing low carbon development strategies, the University has adopted a series of low carbon technologies in its energy supply, including the installation of solar PV system, the upgrade of combine heat and power (CHP) plants, the replacement of old inefficient boilers, the adoption of a thermal heat storage system, and other smart and low carbon technologies such as the use of TermoDeck technology in buildings, and the installation of a district cooling system. This section introduces each of these low carbon energy enabling technologies at UEA.

2.1 Solar PV system

Solar panels were first installed at the ZICER building in 2002 with a total capacity of 34 kW (See Figure 1). The project successfully demonstrated the potential of building integrated PV system at UEA campus. Since then, the University has gradually expanded its solar capacity by installing new solar panels on the accommodation blocks (e.g. 20.7 kW at the Chrome Court) as well as on academic buildings (e.g. 19.8 kW at the Julian Study Centre) (UEA 2014). Since 2013, all new buildings are required to install roof solar panels (UEA 2021a). A list of solar PV installation capacity on the UEA campus can be found on Table 1.

Figure 1 Solar panels installed at the Zuckerman Institute for Connective Environmental Research (ZICER) Building

Despite the growing interest in renewable energy at UEA, solar PV still represents a small share of the total power generation on campus. By the end of 2020, total solar installed capacity was 279.7kW with a total power generation of 273,000 kWh. It represents about 1% of the total electricity consumption at UEA. The average capacity factor of electricity from solar PV is 9.8%, which is slightly lower than that of the national average in the UK[2]. Nevertheless, the development of solar PV system in the future will be key to achieve carbon neutral targets by 2045 at UEA. Potential growth in solar PV installed capacity can be expected in the future.

Building name	Installed capacity (kW)
INTO	99.6
Enterprise Centre	48
Zicer	34
Hickling	21.7
Chrome Court	20.7
Julian	19.8
Barton	18.8
Bob Champion	17.8
Total	**279.7**

Table 1 A list of solar PV system installed at UEA buildings

One of the major concerns with the large-scale deployment of solar PV systems is related to variations in solar power generation. Solar power generation concentrates in a relatively short period of the day and is subject to solar radiation and cloud cover. There are also significant seasonal variations in solar power generation due to longer day times and more intensive irradiance levels in summer. Figure 2 shows the seasonal and diurnal variations in irradiance levels at UEA. Comparing to conventional power generation technologies, solar generation is less capable to match changes in demand alone. Taking into account the daily and seasonal variations in load, UEA has considered a number of options to pair with solar generation, including the use of battery electricity storage and demand response systems. Solar variability and seasonality are known challenges for all solar energy projects particularly in the FCE region (slightly less so in France than the UK). They become more prominent in isolated areas when weak existing grids struggle to compensate for solar variability. Low cost for solar PV however, and gradually reduced cost for batteries will make solar PV and battery combinations a realistic proposition.

[2] According to Statista (2021), the average capacity factor of solar PV in the UK is around 11% between 2012 and 2019. Available from: <https://www.statista.com/statistics/555697/solar-electricity-load-factor-uk/>

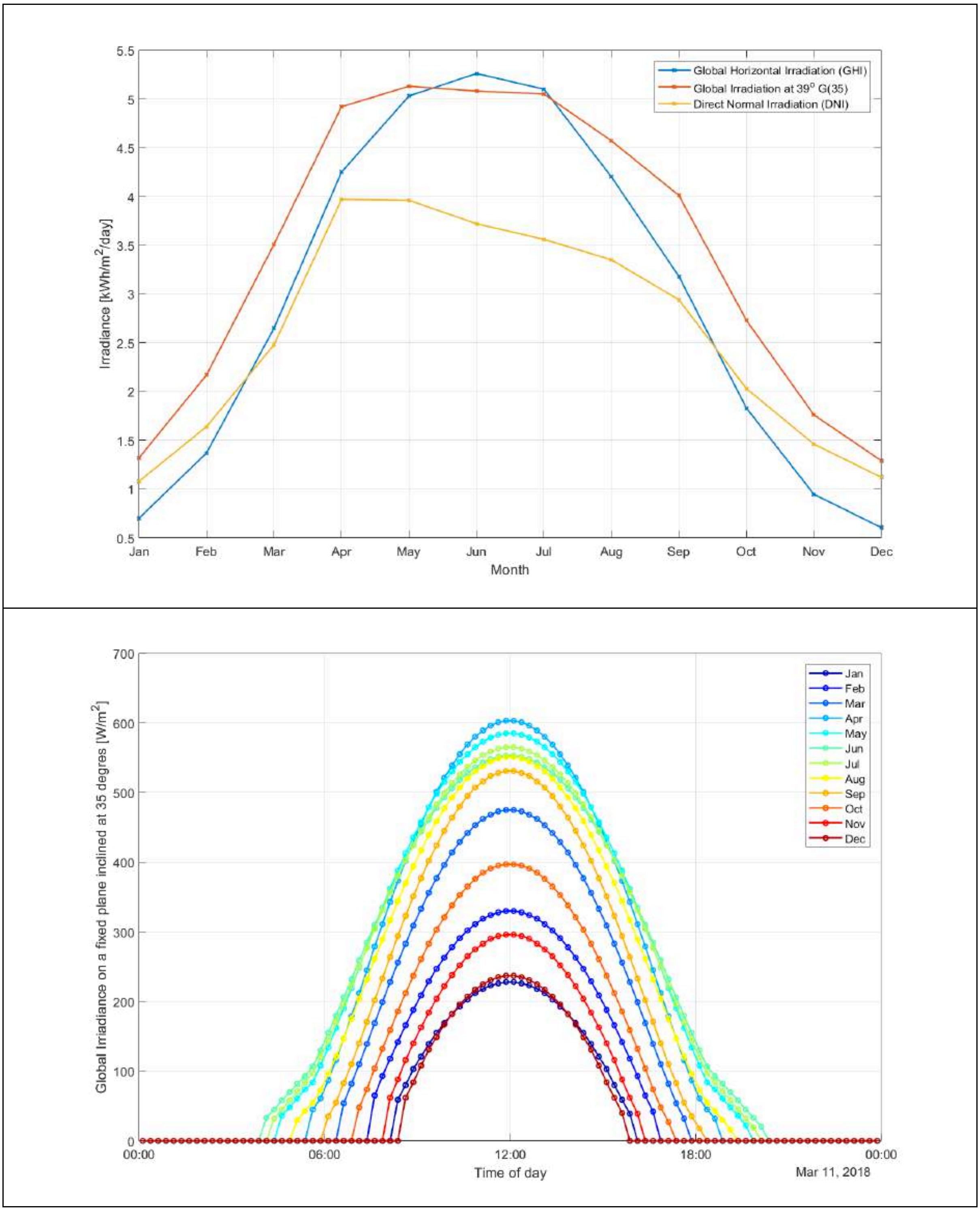


Figure 2 Seasonal and daily variations in irradiance levels

2.2 Combined heat and power plant and gas boilers

CHP plants were first installed at UEA in the late 1990s. Between 1995 and 2000, three CHP units were deployed, each of which with a rated electrical power output of 1 MW. Since then, the CHP units have been the major energy source at campus. On average, about 70-80% of the energy consumed is produced by the CHP plant (UEA 2014). Three types of energy services are supplied by the CHP units. First, over

70% of the electricity consumption relies on generation from the CHP units; second, the majority of buildings on campus rely on CHP units for heating services through the district heating network; third, it provides cooling services through the district cooling scheme, which was first adopted in 2006 (UEA 2021b).

Figure 3 New CHP units installed at UEA

Two new CHP units were installed in 2017 to replace the older models built in the 1990s (See Figure 3). The upgraded CHP units have a proposed lifespan of 15 years, with a total power generation capacity of 4 MW. With higher level of energy efficiency, the upgraded CHP units were expected to help the University reduce carbon emissions by 35% before 2020, compared to 1990 levels.

The deployment of CHP units brings multiple benefits to the UEA:

- It reduces reliance on the grid by producing power and heat on site, therefore improving supply security of the local grid.
- It provides significant savings on energy bills. For example, the upgraded CHP units result in an annual saving of £800,000 due to improvement in energy efficiency. This is a significant reduction in costs given the annual utilities cost at over £4 million pounds between 2014 and 2015 (UEA 2016). The upgrade is part of a £5 million investment between 2015 and 2020 to improve energy efficiency and reduce carbon emissions at UEA campus[3]. Owning to the new investment, total energy cost now is around £3 million per year (UEA 2021a). Figure 4 shows the annual energy costs at UEA.

[3] Other measures include the installation of thermal storage system, the adoption of LED lighting, among others.

- It reduces the carbon footprint of energy consumption by 20% or 5,000 tonnes of CO_2 equivalent each year, comparing to the use of traditional boilers for heating and imported electricity from the grid.

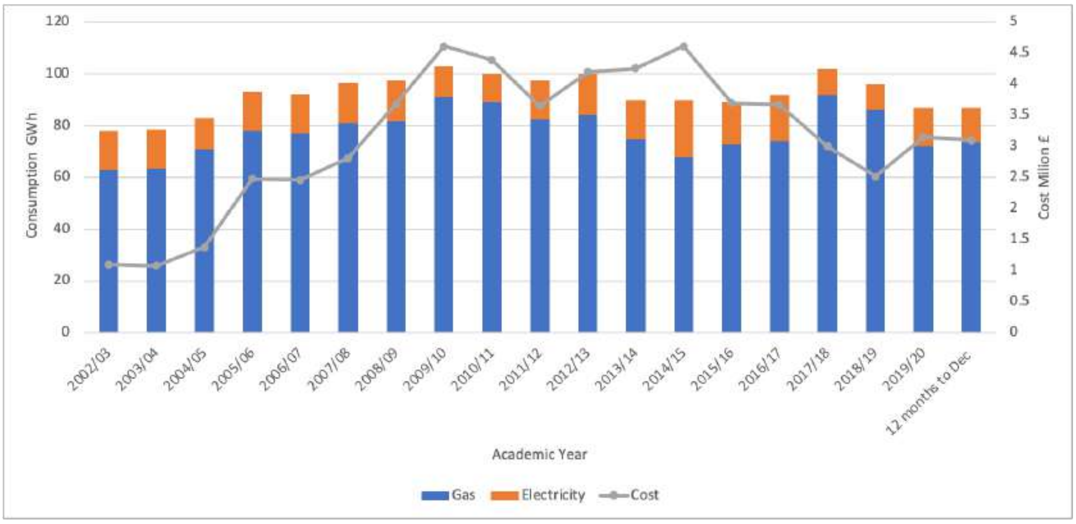


Figure 4 Gas and electricity imports and associated costs

Source: (UEA 2021d)

Apart from the installation of CHP units, UEA has also implemented other measures to improve its energy performance from the supply side. For instance, in Spring 2015, UEA replaced its boilers built in 1964 with three new boilers. With a lifespan of 15 years, the 6 MW each new boiler is used as backup to the CHP units for heating services and can be beneficial to manage the estate growth. Comparing to the old boilers, the new boilers have higher energy efficiency (92 % vs. 75%), that can result in lower cost (savings over 50k per year) and lower emissions (saving over 300 tonnes of CO_2 per year).

Despite the higher energy efficiency, both the upgraded CHP units and boilers rely on gas combustion. It presents a significant challenge in achieving zero carbon emission target since the combustion of natural gas leads to CO_2 emissions. Alternative technologies were considered at UEA. For instance, a biomass gasification plant was planned in the early 2010s. However, the plan was abolished due to technical challenges. Instead, another 1.7 MW of CHP unit was installed, which is now used as a backup unit to the main CHP units. Therefore, total CHP capacity at UEA is 5.7 MW. As UEA has set a target of becoming carbon neutral by 2045, it is believed that CHP units will be phased out and replaced by a decarbonised source of heating and electricity (UEA 2021d).While electricity might be partly directly purchased from the electrical grid, heating might have to be electrified as well with the use of heat-pump technology. As a result, there will be higher reliance on heating and electricity on the electrical grid. The electricity grid in France and the UK is generally considered to be of relatively low carbon emissions as a result of nuclear investment and offshore wind respectively. Where available (not always possible for remote territories and islands) grid electricity (for electricity and heating) will offer an increasingly attractive proposition.

In addition to the above, there are also a few boilers installed in buildings that are not linked to the heating network. However, 95% of the gas were consumed at the main gas consumption units (CHP plants and main boilers), while the rest 5% was used by the local boilers. Apart from domestic generation, about 30% of the electricity supply is imported from the grid.

2.3 Thermal storage system

In 2016, UEA installed two large vessels, each one with capacity of 100 m^3 of hot water (see Figure 5). The installation allows the optimal operation of CHP units and boiler. For example, the three gas boilers are at their maximum efficiencies when they are running at 65% of their rated outputs. In the event when heating demand is greater or less than the boilers' maximum performance levels, the thermal storage system can either store the excessive heat generation or discharge heat to the district heating network. Similar to the gas boilers, the operation of CHP unit may produce excessive heat. When electricity demand rises, CHP units need to ramp up their electricity generation to meet increase in demand. Heat generation coincides with power generation for the CHP plant. However, heat demand may not reach its peak, and excess heat is produced. If no thermal storage system is in place, excessive heat production is dumped, which result in a lower energy efficiency. Therefore, the installation of thermal storage system can reduce energy consumption and associated CO_2 emissions.

Figure 5 Thermal Storage System at UEA

The estimated savings from the deployment of thermal storage system were over £200,000 each year[4]. With a total cost of £600,000, the project has a payback period of within three years. The environmental benefits are also significant. For example, the total CO_2 savings are projected to reach 1,270 tonnes of CO_2 per year[5] (UEA 2021c). Most importantly, and looking into the future, the heat storage system is

[4] It includes £149,000 savings to improve the energy efficiency of the three boilers and £60,000 savings to store excessive heat from CHP units. However, real savings are subject to changes in gas prices.

[5] It includes 735 tonnes of CO_2 savings from the improved energy efficiency of the three boilers and 535 tonnes of CO2 from CHP-related savings.

capable of operating in combination with electrified low carbon heating systems such as heat pumps and demand-side temperature control systems to adjust heat flows.

2.4 Other low carbon technologies and measures

At UEA, 99% of the direct carbon emissions are related to energy consumption in buildings. Between 1990 and 2017, the total floor area of the campus buildings has more than doubled in size. As the University plans to expand its floor area in the future, it is necessary to decouple energy consumption from floor area growth. Therefore, several novel technologies have been adopted to control the environmental impacts of new buildings as well as to manage the energy consumption of existing buildings effectively at UEA.

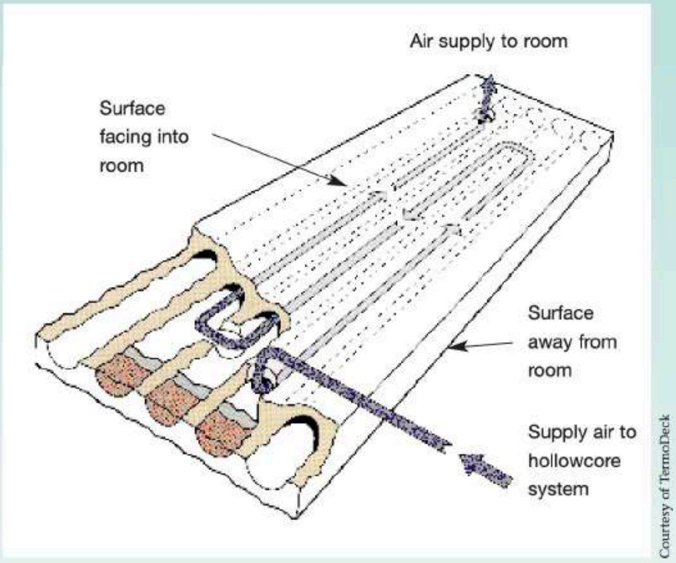
To improve the energy and environmental performances, the design of the new buildings at UEA campus is dominated by two main factors, namely minimising energy consumption on heating and air conditioning and make the best use of daylight. One of the novel technologies that has been adopted at UEA is called TermoDeck, which helps to reduce energy consumption on heating and cooling. TermoDeck makes the best use of thermal mass in winter, which provides inertia against temperature fluctuations by storing heat during daytime. Given that heating represents over half of the total energy consumption in conventional buildings, TermoDeck reduces energy consumption on heating significantly. For example, the adoption of TermoDeck effectively reduces the energy consumption on heating by three quarters at the Elizabeth Fry Building, comparing to other buildings without the technology. In addition, maintenance costs are 50% lower than that of the conventional buildings (Newton 2005). TermoDeck has also been used in other new builds at UEA since then (such as the Zuckerman Institute for Connective Environmental Research building, the Thomas Paine Study Centre, and the Julian Study Centre). The technical features of TermoDeck are shown in Box 1 below.

Hollow core slabs

TermoDeck™ is a patented system which uses the hollow cores in the concrete ceiling slabs as the final part of the air supply duct. The ceiling slabs act as a heat sink and provide radiant heating or cooling and convective heat transfer to the supply air.

Air is supplied through the TermoDeck slabs to the occupied spaces. During the winter the heating system maintains the temperature of the slabs at around room temperature. This ensures that the radiant temperature in the building is close to the internal air temperature. During the summer the slabs are cooled overnight with fresh air. This provides a heat sink for the daytime heat gains.

The TermoDeck design reduces the need for ducting or perimeter heating and so reduces costs and improves space utilisation. It also uses the available thermal mass efficiently.



Box 1: Technical features of the TermoDeck technology

Source: (TermoDeck 1998)

Apart from TermoDeck, a range of technologies were adopted through UEA's REFIT project, with a total investment in energy conservation measures at £1 million. The first phase of the project run between 2017 and 2018, targeting 6 academic buildings and 22 halls of residence blocks (Vital Energi 2019). Implemented measures included:

- The installation of building management system (BMS)[6] to control and monitor energy consumption in buildings.
- An update air handling units & chiller condenser fans to reduce energy consumption.
- An upgrade on lighting system with LED bulbs and smart control systems[7].

The implementation of these energy conservation measures resulted in savings in cost, energy, and CO_2 emissions. Table 2 below shows the total project costs and guaranteed savings from the REFIT project:

Energy Conservation Measure: Price			Guaranteed Savings										
			Electricity		Heat/Gas		ANNUAL TOTAL SAVINGS						
Ref. No.	ECM	Total Project Cost (inc VAT)	Annual Energy Saving		Annual Energy Savings		Total Annual Energy Saving		Total Annual CO_2 Savings		Total Annual Energy Cost Saving		Payback
		£	kWh	%	kWh	%	kWh	%	T CO_2 e	%	£	%	Years
ECM 1	BMS Optimisation	£167,335	72,224	0.4 %	1,136,175	5.4 %	1,208,399	3.2 %	248.0	2.9 %	£43,580	1.7 %	3.8
ECM 2	Ventilation & Fans	£327,101	580,693	3.4 %	-	0.0 %	580,693	1.5 %	146.7	1.7 %	£68,357	2.7 %	4.8
ECM 3	Lighting: LIB LEDs	£550,510	587,128	3.4 %	-	0.0 %	587,128	1.5 %	148.3	1.7 %	£72,542	2.9 %	7.6
Totals: ECMs		**£1,095,453**	**1,240,045**	**7.3 %**	**1,136,175**	**5.4 %**	**2,376,220**	**6.2 %**	**543.0**	**6.3 %**	**£184,479**	**7.4 %**	**5.9**

Table 2 REFIT project costs and savings

Source: (UEA 2017)

With all the implemented measures, the carbon emissions per meter squared of space continued to be reduced alongside the increase in floor areas. Figure 6 shows that the carbon intensity has been reduced by 49% based on the 1990 levels.

[6] BMS refers to technology and control systems that allow granular monitoring of energy consumption at different buildings, which allow the optimised use of energy especially for heating and cooling purposes.

[7] It is expected that less maintenance will be required. For example, the application of LED lightning can lead to less frequent bulb changes given the long lifespan of LED bulbs comparing to florescent bulbs.

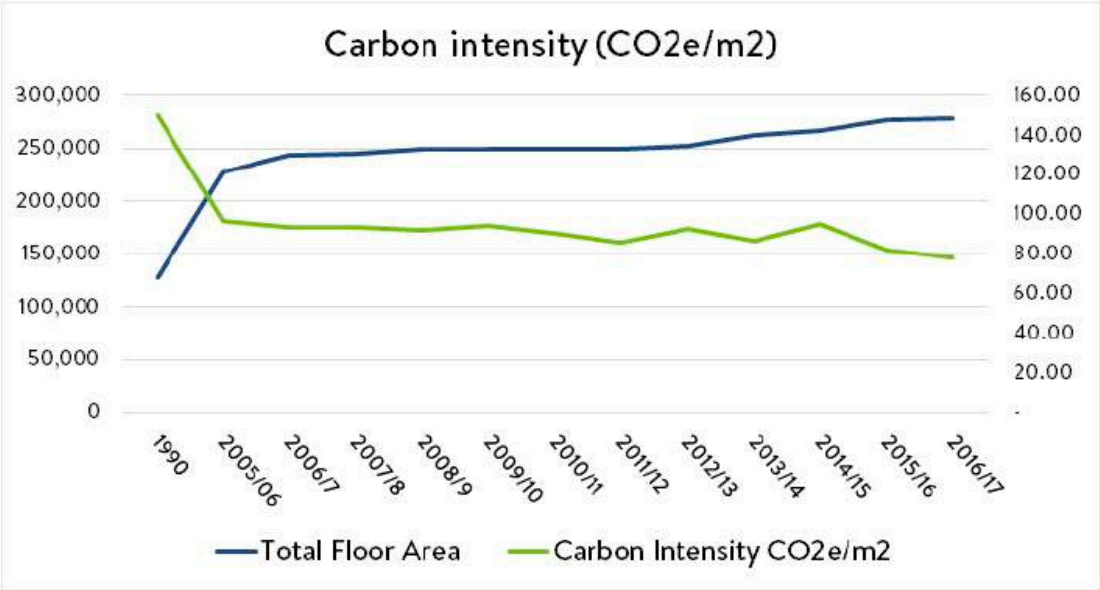


Figure 6 Changes in total floor area and carbon intensity

Source: (UEA 2017) page 12

2.5 Conclusions

UEA has adopted a number of low carbon energy technologies in recent years to improve its environmental and energy performances. From the supply side, UEA invested in solar PV systems, installed and upgraded gas CHP units, upgraded three gas boilers, and installed a thermal storage system. The applications of low carbon energy technologies have effectively reduced the CO_2 emissions at UEA campus. In addition, it has resulted in savings in energy cost due to energy efficiency improvements. From the demand side, UEA adopted novel technologies to reduce energy consumption in its buildings. For example, the adoption of TermoDeck technology reduces energy consumption for heating significantly; the installation of BMS allows for more granular control of energy consumption in different buildings; the upgrade of LED lighting saves energy consumption for lighting as well reduce costs for maintenance.

2.6 References

Newton, M. (2005). "Client Testimonials: Elizabeth Fry Building, University of East Anglia UK." Retrieved 18 August, 2021, from https://www.termodeck.com/satisfaction.html.
TermoDeck. (1998). "The Elizabeth Fry Building, University of East Anglia." New Practice Final Report 106 Retrieved 18 August, 2021, from https://www.termodeck.com/Filer/pdf/BRE_EFRY_REPORT.pdf.
UEA. (2014). "Environmental Report." Sustainable Ways Retrieved 18 August, 2021, from https://sites.uea.ac.uk/documents/3154295/9533899/UEA+Environmental+Report+2014_upload+v1.pdf.
UEA (2016). Target 2020. Sustainable Ways - Energy and Carbon, University of East Anglia.
UEA (2017). Annual Environmental Sustainability Report 2017. Sustainable Ways, University of East Anglia.

UEA. (2021a). "Energy Efficiency and Carbon Reduction." Retrieved 18 August, 2021, from https://www.uea.ac.uk/about/university-information/sustainability/sustainable-campus/energy-efficiency-and-carbon-reduction.
UEA. (2021b). "Projects: District Cooling System." Retrieved 18 August, 2021, from https://www.uea.ac.uk/web/about/university-information/sustainability/projects/-/asset_publisher/PeaY8phFOiQa/content/2005-2010-district-cooling-and-thomas-paine-study-centre?_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_redirect=https%3A%2F%2Fwww.uea.ac.uk%3A443%2Fweb%2Fabout%2Funiversity-information%2Fsustainability%2Fprojects%3Fp_p_id%3Dcom_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_cur%3D2%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_delta%3D6%26p_r_p_resetCur%3Dfalse%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_assetEntryId%3D3291846#TitleBar.
UEA. (2021c). "Projects: Thermal Stores." Retrieved 18 August, 2021, from https://www.uea.ac.uk/web/about/university-information/sustainability/projects/-/asset_publisher/PeaY8phFOiQa/content/thermal-stores?_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_redirect=https%3A%2F%2Fwww.uea.ac.uk%3A443%2Fweb%2Fabout%2Funiversity-information%2Fsustainability%2Fprojects%3Fp_p_id%3Dcom_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_cur%3D4%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_delta%3D6%26p_r_p_resetCur%3Dfalse%26_com_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_PeaY8phFOiQa_assetEntryId%3D3246862#TitleBar.
UEA (2021d). Sustainability Board Meeting Minutes April 2021, University of East Angalia.
Vital Energi. (2019). "REFIT project: University of East Anglia." Retrieved 18 August, 2021, from https://www.vitalenergi.co.uk/our-work/university-of-east-anglia/.

3 Optimising Performance of the Low Carbon Energy System at UEA

This section introduces the performance optimisation of the low carbon energy technologies at UEA. Through better coordination among different technologies, an integrated energy system can effectively reduce energy consumption and associated CO_2 emissions, improve energy supply security of local grid, and reduce costs. At UEA, the operation of the CHP plant reduces the reliance on grid imported electricity, therefore safeguarding the secure supply of electricity on campus. The operating efficiency of CHP is greatly improved when combined with the thermal storage system. Excessive heat production from CHP can be stored and distributed more effectively through its district heating and cooling system. One other important contribution by the thermal storage system is to maximize the operating efficiency of gas boilers, which can maintain at its optimal performance levels even during low demand period. In addition, the UEA has also adopted other technologies/measures that reduce its energy consumption through energy efficiency improvement, such as the use of TermoDeck technology consumption in buildings.

This section first illustrates the integration of different technologies at UEA in order to optimise the operation of the system in Section 3.1. Then it examines the technology options for future energy supply at UEA in Section 3.2.

3.1 An integrated energy system at UEA

3.1.1 Optimising performance of existing low carbon technologies

The optimal performance of UEA's energy system depends on several key factors. First of all, the adoption of CHP reduces emissions related to imported electricity and improves the overall energy efficiency of energy provision. CHP units produce electricity via internal combustion engines, which produce a significant amount of heat at the same time. For a conventional gas unit excess heat production is dumped via the cooling system (usually into the air), resulting in losses in energy conversion. For instance, the average thermal efficiency of combined cycle gas turbine stations is around 48% in the UK (Statista 2021), comparing to 80% for a CHP plant when heat is utilised. At UEA campus, both academic and residential buildings require heat supply. Through the construction of a heat supply network, a CHP plant is best suited to supply both heat and power on campus as it allows for better energy efficiency comparing to serving the two types of energy services separately.

Apart from heating demand, there is also demand for cooling for both academic research purposes (such as refrigeration for sensitive materials) and use for comfort in summer. The UEA has also a district cooling system which uses waste heat from CHP plants and produces cold water through an absorption chiller unit. The new system replaced the previous electricity-driven compression refrigeration and provides cooling to laboratory equipment and areas prone to overheating. At least two benefits can be seen from the adoption of district cooling system. First, it helps reduce electricity consumption for cooling purposes, therefore leads to cost and emission savings on campus. Second, it reduces the need for refrigerants, which reduces the emission of many gases that have much higher global warning potential (GWP) than CO_2. Figure 7 below shows the total refrigerant loss, based on a calculation of the CO_2 equivalent of several greenhouse gases.

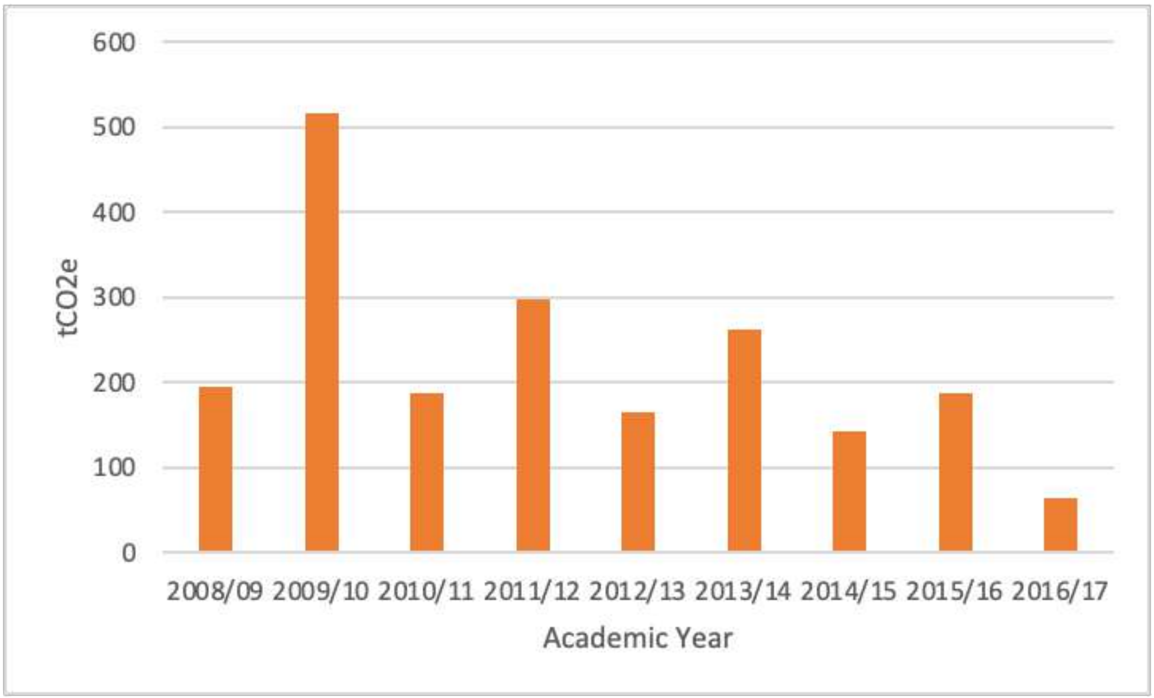


Figure 7 Total refrigerant loss (tCO2e)

Source: (UEA 2017)

As mentioned above, there are significant variations in heat and electricity demand, which do not usually peak at the same time. During events when electricity demand is high and heat demand is low, excessive heat production from the CHP plant is not needed. Without a proper heat storage facility, the heat will be transferred to the environment, resulting in a loss in energy efficiency and unnecessary emissions. To better utilise the energy sources, a thermal storage system is installed at UEA campus to store the excessive heat production. It can release the heat when there is increase in heat demand, without operating the CHP plants. Therefore, the thermal storage system reduces energy consumption through storing heat for later use. In addition, the thermal storage system is used to store heat from gas boilers that allow the boilers to operate at their optimal operating levels (at approximately 60-65% of rated capacity). Similar to the CHP plant operation, that means that when heat demand is at its low level, gas boilers can still run at their optimal capacity. Additional heat production is stored for later use. Therefore, thermal storage system allows for better coordination among energy supply facilities on UEA campus.

The secure supply of electricity and heat requires demand to be met with supply at all times. Thermal storage system allows for storage of heat when production is higher than demand. One of the other options is through the participation of demand side in the optimising performance of low carbon technologies. At UEA, electricity and heat demand show significant daily and seasonal variations. For example, there are large differences in heating demand between summer and winter. It usually reaches peak demand in winter, which accounts for 70% of the annual demand. A sharp decline in demand usually happens in May when summer holiday season starts, before reaching the lowest levels in July and August. That is a result of a combination factors such as reduced number of people on campus and reduced heating demand because of warmer weather. While thermal storage system can address short-term variations in demand, it cannot sustain for a long period of time such as seasonal variation. On the other hand, electricity demand does not show as significant seasonal variations. On average, 52% of electricity is consumed in winter, while 48% is consumed in summer. Instead, electricity demand varies at different times of a day. For instance, it usually reaches peak consumption in the late afternoon between 4 and 8 pm, similar to the peak demand period at national level. There are also significant differences in electricity demand between weekday and weekend. On average, demand is 20% lower on weekends during daytime.

To address both the short-term and long-term variations in electricity and heat demand, the University has incorporated several different technologies to manage energy consumption from demand side. The first set of measures address the improvement in energy efficiency, therefore reducing overall energy demand on campus. For example, the adoption of TermoDeck technology, the use of BMS, and the upgrade of LED lighting all contribute to the overall energy efficiency improvement. These measures allow for decoupling of energy consumption from growths in floor size and support better use of energy in buildings. In addition to the energy efficiency improvement measures, UEA is also advanced in the broader demand response domain with significant experience of frequency response applications on campus[8]. These highly automated systems allow for rapid identification of energy use reduction opportunities on campus when there is a requirement to balance energy supply and demand. Less automated systems are of equally high importance as they can be applied more widely but require better information flows and active agency by the campus energy users, students and employees.

3.1.2 User engagement

Most of the attention of the technological options described above belong in the broader category of top-down solutions. It is characteristic of these options that they are imposed by central planning within the organisation and are very common in almost all attempts for low carbon energy transition. In such approaches the connection between energy systems and their users can be a greater asset since infrastructure is more prominent. Additionally, the results of energy unavailability can be felt more since, in isolated systems there is a lack of alternatives. Therefore, that raises the argument for innovation that enables a different paradigm to the top-down approach i.e. a bottom up approach. It is clear that reorganising a complete bottom-up campus energy system is capital intensive and has to be timed appropriately, to allow for existing systems to reach the end of their technical and financial lifespan. There is, however, still scope for innovations even if they do not provide a complete bottom-up solution, they at least could help in re-balancing the overall system.

UEA commits to improve its sustainability credentials by engaging with its staff and students. Several programmes have been implemented, including the Green Impact Programme, Sustainable Societies, and Staff Champions. For example, the Green Impact Programme invite teams from all departments to participate in and contribute to the Programme with the primary target of increasing their environmental awareness and improving energy performances (UEA 2021b). The Programme aims at encouraging behaviour changes by staff and students, which leads to more sustainable consumption of resources at UEA. An inclusive approach is adopted as everyone interested in the programme can participate. Main actions used by participating teams include holiday shutdowns and awareness day events. The Sustainability Team from Estates also provides support to the teams by offering suggestions and giving feedbacks on selected activities. Awards are presented each year to prize teams and individuals with the best achievements in terms of programme design, action implementation, and final outcomes (e.g., energy savings or carbon emission reduction). The Green Impact Programme has greatly improved the

[8] Frequency response is introduced in Section 4.

environmental awareness of both staff and students in general, but also the understanding of low carbon transition in particular. For example, in the Green Impact programme 2017 – 18, a total of over 26,000 kilograms of CO_2 and £7,000 were saved. 1455 staff were engaged in 644 greening actions. 16 teams with 78 members participated the programme. 54 students were trained as auditors and project assistants (UEA 2017).

While UEA has made several attempts to engage its community in action for the low carbon energy transition this has not generally included the empowerment of the campus users to become responsible for their own energy use. That is something that the ICE project has first attempted and that is discussed in more detail in Section 2. Furthermore, consumer engagement can happen in different formats at different locations. As mentioned in previous subsections, UEA has been active in engaging with both staff and students through various means in order to support better communications on issues related to the energy transition at UEA. Apart from the measures introduced, one of the other ways that offer good communication channel is through an exhibition.

In the ICE project, the SDEF team prepared an exhibition that demonstrates energy transition in general and several themes related to energy transition in particular. The concept of the energy transition is introduced at the beginning of the exhibition, with a special focus on changes in individual behaviour. It addresses the role of citizens in the energy transition, and how they can contribute to the transition. Questions are included to stimulate thoughts on behavioural changes, for example, how can we consume better and consume less in the future? Following that, the exhibition addresses three different themes, including sustainable mobility, sustainable urbanism, and optimised energy systems. In each theme, examples are provided on how citizens can participate in and contribute to energy transition. For instance, for sustainable mobility, ideas on car sharing, use of soft mobility (e.g. bicycles and walking) and the use of public transport are introduced. These measures can be useful in reducing associated emissions in the transport sector, which has been largely relied on fossil fuels. The exhibition introduces urbanism and associated concepts and approaches to achieve sustainable urbanism, including the concept of thermal regulations, the idea of hedgerows, as well as other novel approaches to better manage energy consumption in residential, commercial, and industrial buildings. For the optimised energy system, several new energy models/technologies are included, such as anaerobic digestion, the smart grid system, marine technologies, among others. The three themes are interlinked, which provides a novel approach to simulate thoughts on specific issues as well as the energy transition in general.

Throughout the exhibition, relevant information on energy transition can be disseminated via interactions with participants. For example, participants can raise questions on issues that they are interested in and answer questions to reflect their ideas on how to make the transition happen.

The contents of the exhibition were translated into English in order to allow its dissemination at various locations in the UK. Appendix I provides further details of the exhibition in both French and English. Unfortunately, due to COVID-19 restrictions, the exhibition only happened in France. Figure 8 shows the preparation of the exhibition about energy transition. The exhibition was held for two weeks. Exhibition in the UK was not possible due to concerns on health and safety issues. Nevertheless, the prepared posters and ideas behind the exhibition can be used in the future when possible.

Figure 8 Preparation for the exhibition about energy transition

3.2 Future plans on building a low carbon energy system at UEA

UEA’s work for climate change abatement can be exemplified by its commitments to reduce GHG emissions at different timeframes. For instance, in an earlier commitment, the University aimed at reducing carbon emissions by 80% by 2050 comparing to the 1990 level (UEA 2016). Alongside the long-term emission reduction target, it had also developed a series of activities and programmes to gradually reduce the carbon emissions in the near term. For example, in 2015, the Sustainability team announced the implementation of the Energy and Carbon Reduction Programme (ECRP). The Programme set out a series of targets and actions to achieve a low carbon energy system on campus. The first phase of the ECRP was implemented between 2015 and 2020. Two main targets were set, including:

- Reduce carbon emissions (Scope 1 and Scope 2 emissions)[9] by 35% by 2020, based on the 1990 levels.
- Reduce energy consumption by 25% by 2020[10], based on 2013-14 levels.

Despite growing effort to reducing GHG emissions, challenges remain with the on-going expansion of floor area at UEA, which lead to growing energy demand on campus. As of April 2021, the University failed to meet its near-term carbon emission target by 2020 in the ECRP, which only showed reductions by 18% over 1990 levels (vs 35% target). However, there has been a significant decline from its peak emission levels in 2014/15 by 37%. Figure 4 shows the future trajectory of building related emissions, which account for vast majority of the total emissions at UEA. The 2020 energy consumption target was not met either. There was 4% reduction in energy consumption over 1990 levels and 13% reduction from the 2014/15 peak consumption levels. Indeed, the University has seen gradual decline in annual CO_2 emissions after reaching its peak in 2015 (see Figure 9).

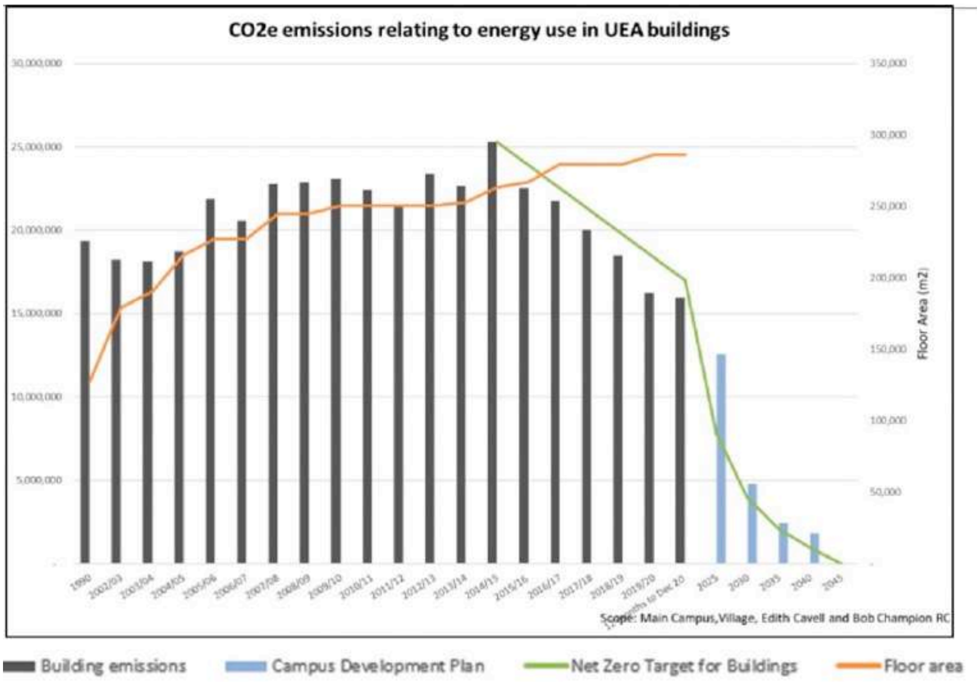


Figure 9 UEA CO2 emissions related to energy use in built estate

Source: (UEA 2021c)

Recently, UEA has developed a NetZero carbon management plan to strengthen its delivery in reducing CO_2 emissions. Alongside the new NetZero Plan, on 11 February 2021, the Vice-Chancellor of UEA announced a new plan to become carbon neutral. The Plan introduces several updated energy and carbon targets, including over 80% campus (Scope 1 and 2 emissions) emission reduction by 2030 and 100%

[9] Scope 1 emissions include direct emissions resulted from owned and controlled sources. Scope 2 emissions includes indirect emissions from electricity, heat and steam consumption, which are produced by others and imported for use to the University.

[10] Target date extended to July 2021.

in total (Scope 3)[11] emission reduction by 2045 or earlier, both of which based on the 2014/15 baseline. One key aspect of the commitment is that the University pledges not to rely on carbon emission offsetting, which means a complete move away from fossil fuels for its energy provision by 2045 (UEA 2021a)[12].

The NetZero Plan has proposed a few measures to reduce energy consumption and associated emissions. Two emission reduction related activities are addressed, namely building and travel-related emissions. For building related emissions, there are four areas to focus on, including energy demand reduction, energy efficiency increase, renewable energy development on campus, and renewable energy development offsite. Apart from the building-related emission reduction, UEA also sets out plans for emission reduction in traveling, which accounted for one fifth of the total emissions in 2015. In 2018, over 55% of the UEA staff used private cars for their commute. In addition, the use of air transportation by UEA staff and international students accounted for a quarter of the travel-related emissions. While some of that air travel is essential for UEA research meetings and conferences, there are ways to reduce emissions by selecting only those journeys necessary (Chalvatzis and Ormosi 2021). UEA adopts the Avoid-Shift-Improve framework, which is to avoid unnecessary travel, shift to low pollution transport and improve uptake of electric buses and cars. More details on future mobility strategies can be found in Deliverable 3.1.1

Carbon emission reduction targets can have significant implications on the low carbon energy strategies at UEA. For instance, between 2020 and 2025, the University proposes to conduct technology and site review to develop plans to decarbonise heating supply on campus. It is followed by the implementation of the Plan through the adoption of heat pumps between 2025 and 2030. Over the longer term, UEA will consider the combination of heat pumps and hydrogen to provide heat supply. As for electricity generation, the university proposes to expand its solar PV capacity (and explore the potential installation of a wind turbine) together with the installation of electric energy storage system between 2020 and 2030. For instance, 650kW of solar PV has been proposed to be installed at the Sportspark building. The successful implementation of the project will make total installed capacity of solar PV close to 1MW at UEA.

One other key measure during this period is to phase out the natural gas CHP plant by 2028, which has been a major source of domestic energy provision at UEA since its first operation (UEA 2020). When initially installed gas CHP was considered as a favourable low carbon technology since imported electricity from the grid would have higher carbon content. Within the FCE area, France has been a world leader in low carbon electricity for several decades, owned mainly to its vast civil nuclear energy programme. The UK's power supply has previously relied on a mix of nuclear, coal and natural gas. With coal phase out in the UK and its replacement predominantly with renewable energy sources, the UK's power grid has seen rapid emissions reduction. Specifically, the power grid in the UK has seen rapid decline in carbon emissions per unit of generation, represented by the transition away from coal and the fast uptake of renewable energy sources (particularly offshore wind energy). For instance, in 2020, a record of 5,167 hours of coal-free grid operation has been observed, compared with 3,666, 1,856 and 624 hours in 2019, 2018 and 2017. The average CO_2 emissions per unit of electricity consumed (known as carbon intensity) were 181 grams CO_2/kWh in 2020 (National Grid ESO 2021). The lowest

[11] Scope 3 emissions includes all other indirect emissions such as emissions resulted from the supply chain of the organisation.

[12] If offset was essential, the university would prioritise local sources.

daily carbon intensity was 46 grams CO_2/kWh, which underline the progress towards a carbon free power grid in the near future. A more accurate way to assess electricity grid emissions would be by looking into the life cycle emissions, as these include the complete fuel journey but even though that is technically possible (Li et al. 2018), it is not taken into consideration in most assessments.

The tipping point for gas CHP to not to be favourable in terms of emission reduction is quickly approaching, despite its high energy efficiency levels. Existing gas CHP based energy system will need to be phased out as the consumption of fossil fuels needs to be minimised to decarbonise energy supply on campus. It is a necessary step-forward to achieve net zero emissions at UEA by 2045. Thus, efforts need to be made to replace gas CHP for both electricity and heating services. One of the alternatives for heating supply is the use of heat pumps, while other options such as biomethane, BioSNG or hydrogen can also become more favourably in the future. Similar to the existing thermal storage system that provides a buffer to heat supply, it is imperative to integrate more flexible units to optimise the operation of the energy system at UEA when renewable energy sources are adopted to replace CHP plants. Such flexible units include, but are not limited to, battery storage systems and demand-side technologies, which require new investment and stringent planning. Nevertheless, there is still need to reduce heat demand at UEA through energy efficiency improvements and building retrofits (Burohappold Engineering 2018).

Besides, with the accelerated decarbonisation in the power generation at national level, UEA has plans to increase electricity import from the grid in the future. This option is not without its own challenges though. Most importantly, these are linked to potential increase in costs and the required upgrade for the distribution networks. This issue is at the heart of the difficulties faced by the remote territories of the FCE region where constrained network capacity presents limitations even for areas which are not islands. Indeed, there has always been budget challenges in the implementation of low carbon solutions. Furthermore, the University had to postpone several low carbon energy projects recently due to COVID-19 restrictions. It presented a significant challenge for the University to fulfil its near-term climate targets both as a result of financial challenges and as a result of the changed modes of work and operations in general.

Indeed, several proposed measures in the energy transition at UEA are covered in the ICE project. For example, one of the important measures to control energy demand is related to changes in consumption behaviour. In the UEA case study, the ICE project demonstrates a plan for energy consumption management at student residences through behaviour change[13]. In addition, energy efficiency improvement is linked to the adoption of smart technologies that enables the optimal use of energy.

3.3 Conclusions

This section introduces the optimisation of the low carbon technologies operation and the future energy strategies at UEA. Apart from the better operating efficiency, the low carbon energy technologies are integrated with each other and help the UEA to reduce energy consumption and carbon emissions. The CHP plant and gas boilers reach their optimal operating efficiency with the installation of a thermal storage system. The thermal storage system stores excessive heat production for later use through the district heating and cooling systems, therefore an example of better utilisation of resources. In addition,

[13] See Deliverable T5.1 for details.

the UEA has also adopted other technologies/measures as well as engaged with staff and students in achieving its climate targets.

The University has committed to a net zero carbon emission by 2045, a significant driver for low carbon energy strategies at UEA. All fossil fuel-based energy generation will be replaced by renewable energy sources, such as solar and wind. Given the variability of renewable generation, flexible sources are needed such as battery storage systems and demand responses. Other energy and novel technologies, such as hydrogen, are also important to the future energy plan at UEA.

3.4 References

Burohappold Engineering (2018). UEA Utilities Infrastructure Strategy - Stage 1.
Chalvatzis, K. and P. L. Ormosi (2021). "The carbon impact of flying to economics conferences: is flying more associated with more citations?" Journal of Sustainable Tourism **29**(1): 40-67.
Li, X., K. J. Chalvatzis and D. Pappas (2018). "Life cycle greenhouse gas emissions from power generation in China's provinces in 2020." Applied Energy **223**: 93-102.
National Grid ESO. (2021). "Record-breaking 2020 becomes greenest year for Britain's electricity." Retrieved 28 September, 2021, from https://www.nationalgrideso.com/news/record-breaking-2020-becomes-greenest-year-britains-electricity.
Statista. (2021). "Thermal efficiency of combined cycle gas turbine stations in the United Kingdom (UK) from 2010 to 2019." Retrieved 28 Sep, 2021, from https://www.statista.com/statistics/548943/thermal-efficiency-gas-turbine-stations-uk/.
UEA (2016). Target 2020. Sustainable Ways - Energy and Carbon, University of East Anglia.
UEA (2017). Annual Environmental Sustainability Report 2017. Sustainable Ways, University of East Anglia.
UEA (2020). NetZero UEA: What is it and how to achieve it? Stakeholder workshops final report, University of East Anglia.
UEA. (2021a). "Energy Efficiency and Carbon Reduction." Retrieved 18 August, 2021, from https://www.uea.ac.uk/about/university-information/sustainability/sustainable-campus/energy-efficiency-and-carbon-reduction.
UEA. (2021b). "Green Impact Programme." Retrieved 18 August, 2021.
UEA (2021c). Sustainability Board Meeting Minutes April 2021, University of East Angalia.

4 Implemented Interventions at UEA

Among others, there are two key low carbon energy technologies at UEA, namely the smart heating system and the frequency control. Both technologies draw on resources from the demand side, which is complementary to the optimisation of the UEA energy supply system (as presented in the previous sections).

This section starts with the context on the changing structure in supply due to penetration of renewable energy sources and gradual phase out of fossil fuels in the power system. It then links to the increasing need of balancing services, one of which comes from demand side management (DSM). Section 1 gives a description of DSM in terms of definition, types, applications, and benefits. It is followed by an introduction of the smart heating retrofit in Section 2. It includes the background information, system specifications, benefits and challenges of the system. Another key aspect in the integrated energy solution at UEA is the adoption of frequency response. In fact, frequency response is part of the technological solution for DSM, which are growing fast in the UK in recent years. Frequency response (FR) as part of the general DSM provides balancing services in the UK, which is the focus of Section 3. This section starts with an introduction of FR, its definition, types of FR, as well as requirements of providing FR and payments. This information provides the status quo of FR in the UK. Then it introduces the Dynamic Demand technology installed by OpenEnergi at the UEA campus to enable the participation of firm frequency response at the UK power market.

4.1 Demand side management

Despite the on-going energy transition, the organisation of the electricity sector reflects the economics and technology of the 20th century in most countries. The UK is one of the world's leaders in the power sector reform. Its experience in building a liberalised power market since the early 1990s has been introduced to and implemented in other countries (Pollitt et al. 2017). Earlier power sector reform focused on the separation of competitive activities from natural monopolies, the regulation of transmission and distribution networks, and the creation of an energy-only market. Since then, the reform has evolved substantially, especially after the review of the power system towards the UK's decarbonation goals. Therefore, a radical change to the architecture of the UK electricity market was introduced in 2013, known as the Electricity Market Reform (EMR). In the EMR, the UK government introduced a few policy instruments to decarbonise the energy system in particular the electricity sector, including regulatory restrictions on coal consumption and proposed exit plans, introduction of capacity auctions, feed-in-tariffs (FiTs), contracts for difference (CfD), and carbon price floors. These policy measures encourage the growth of decarbonised, clean and sustainable energy sources (such as wind and solar energy) in replacement of fossil fuels.

The earlier power sector reform and the EMR policies have been successful in promoting the penetration of renewable energy sources and reducing CO_2 emissions from the electricity sector. Figure 10 presents the changes in power mix between 1990 and 2019 in the UK. It shows that wind and solar generation grew from nil in 1990 to 77.3 TWh in 2019. During the same period, coal power generation declined from 229.8 TWh to 6.9 TWh.

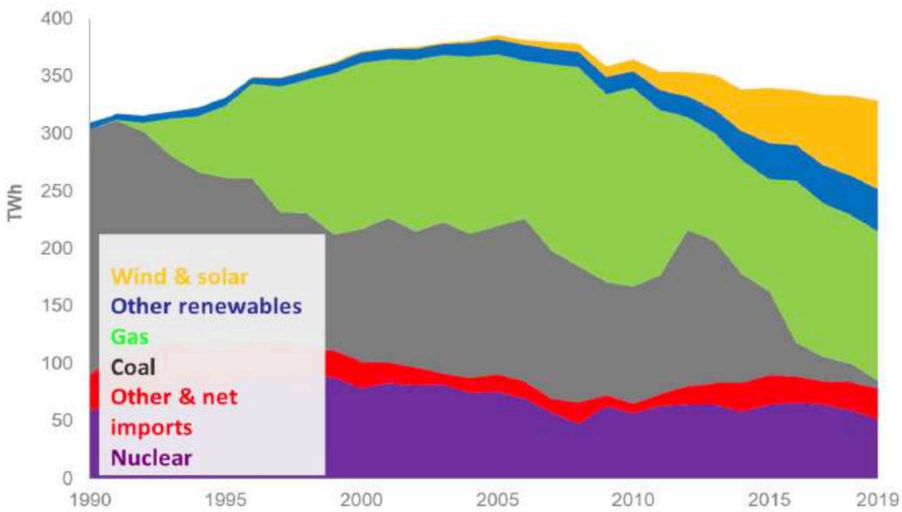


Figure 10 Electricity generation by fuel type between 1990 and 2019

Source: (BEIS 2020)

In particular, EMR is considered as a step forwards to achieve a decarbonised power system in the UK since it introduced policy instruments to support the growth of renewables, limit the use of coal, and improve the reliability in power supply (Grubb and Newbery 2018). On the other hand, the increasing levels of renewable energy penetration and their variable nature in generation have driven the increase in balancing costs. Figure 11 shows the balancing cost as share of generation cost and the increase in balancing price due to increase in share of renewables in the GB market. It shows that balancing cost as share of generation cost has been increasing since 2010. A spike was observed in early 2020 due to lower demand (because of COVID-19 Pandemic) and lower electricity prices (because of high renewable generation). Furthermore, as the level of renewable energy penetration increases, the balancing price will further increase.

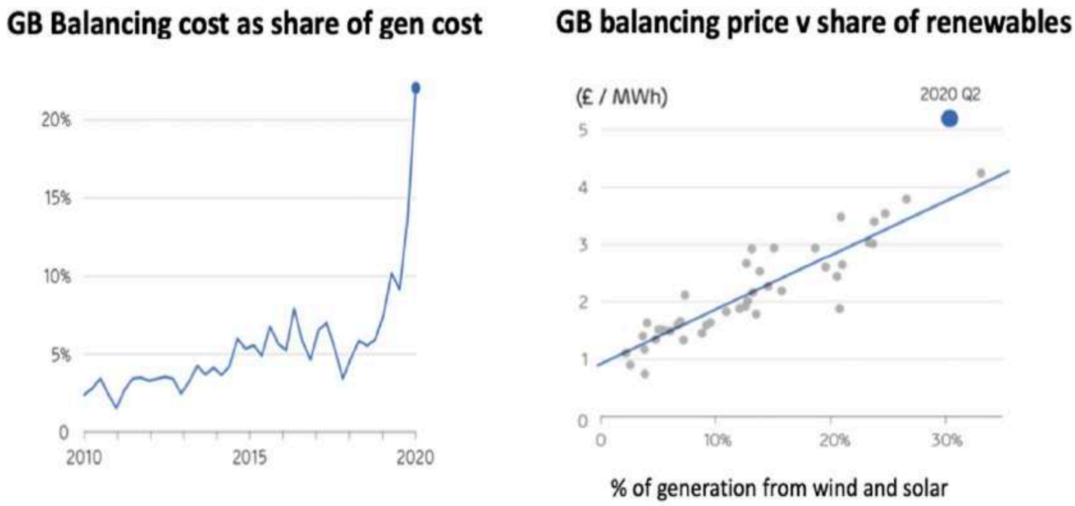


Figure 11 Renewables penetration rises and cost of balancing increases in GB

Source: (Drax 2020)

The growing trend of balancing costs reflects the increasing importance of flexible sources in the power system. Flexibility can be defined in different ways. The IEA, for instance, defines flexibility as the ability of the power system to respond in a timely manner to variations in electricity supply and demand (Chandler 2011). Other definitions of flexibility of the system also refer to the ability to cope with uncertainty and volatility at minimum cost and to ensure system reliability.

Traditionally, flexibility services have relied on large-scale power stations, in many cases fossil fuel-based plants. The decarbonisation of power systems introduces the necessity to explore new sources of flexibility. With the penetration of renewable electricity and closure of existing conventional power stations (as has happened with several coal-fired power stations in the UK), flexibility alternatives include increasing the flexibility of the remaining conventional generation sources, relying more on the grid and interconnection with other systems, as well as storage and demand side measures. The roles of these different sources of flexibility will depend on a system's resources, the alternatives available, and what combination of resources is most economic today and in future when environmental pressures will be greater. In general, the aim is to develop and use the flexibility resources that minimize system costs and ensure system reliability, while also meeting other policy objectives, notably decarbonization as well as democratization and empowerment of consumers.

4.1.1 Definition of demand side management

The concept of DSM was originated in the 1970s in response to the growing concerns on the security supply of oil and environmental impacts of electricity generation in the United States. DSM programs became popular in the 1980s when utilities were encouraged to pursue least-cost or integrated resource planning principles (Eto 1996). The development of DSM programs reflects the changes of strategy in power system planning, which addresses that DSM could be more cost effective than the traditional notion of bulk power generation and transmission. Nowadays, DSM has become an important instrument in the power system operation in many countries.

There is no agreed definition of DSM. Some definitions are more general, while others offer more details. A list of definitions is given below.

"Demand side management is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load. Utility programs falling under the umbrella of demand-side management include: load management, new uses, strategic conservation, electrification, customer generation, and adjustments in market share."

(Gellings 1985)

"Demand side management is the planning, implementation and monitoring of utility activities that are designed to influence customer use of electricity."

(Gelazanskas and Gamage 2014)

"DSM can be defined as modifications in the demand side energy consumption pattern to foster better efficiency and operations in electrical energy systems."

(Behrangrad 2015).

In general, the concept of DSM refers to the changes in energy consumption patterns from the demand side in support of power system operation.

4.1.2 Types of demand side management

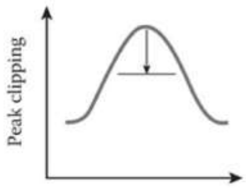
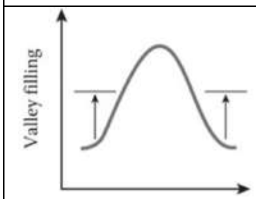
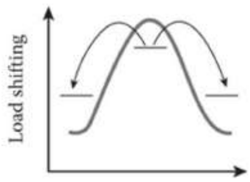
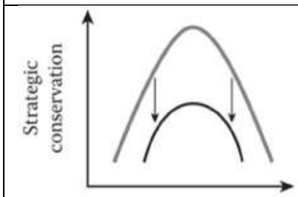
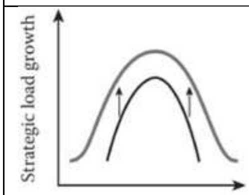
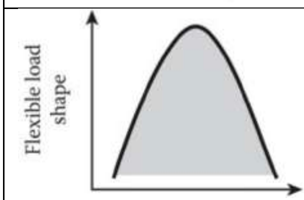
Changes in energy consumption patterns usually include two types of activities. The first type of activities focuses on the energy consumption reduction over a long period of time through energy efficiency improvement, which are also known as energy saving activities. Energy can be saved by changing consumption behaviour (such as reduced room temperature in winter season) and switch to low energy consuming technologies (such as the replacement of old inefficient appliances with more efficient ones). The former usually incur low or no cost, while the latter requires capital investment. One of the most significant examples in energy saving activities is the transition to efficient lighting. The replacement of traditional incandescent bulbs with energy-efficient lightbulbs such as halogen incandescent, compact fluorescent lamps (CLF), and light emitting diodes (LED) bulbs can reduce energy consumption by up to 80% (Ganandran et al. 2014). At national level, the transition to efficient lightning can lead to significant energy savings. For instance, a recent study on energy savings from the deployment of LED technology in India shows that annual energy savings amounted to 30 billion kWh between 2014 and 2018 (Kamat et al. 2020). What is important as a defining characteristic of such an intervention is that it does not require any significant user involvement, other than in terms of purchasing and installing the new light bulbs. Once that happens, the energy savings happen purely because of the new technology's merits, without the user making any behavioural changes in terms of reducing the use of lights and so on.

The other type of activities focuses on energy consumption in reflection of the general conditions in supply and demand. It usually leads to a different consumption pattern, referred to as demand response. Contrary to the behaviour change above, this type of behaviour change results in modification of consumption in a short period of time. These changes are usually driven by effective tariff design and supportive incentives that encourage behaviour change. For example, time-of-use (TOU) tariffs are used to distinguish between peak and off-peak periods, which encourage consumers to switch their consumption to off-peak periods when energy prices are low; critical peak pricing is used to charge a large multiple of normal tariffs during periods of system stress, which encourage consumers to reduce consumption during these critical peak periods and switch their consumption to another period when price is low.

The demand side is an important element to the energy transition. First, consumer participation is vital to achieve carbon neutrality target. Power system flexibility is crucial in allowing more use of low carbon energy sources which produce electricity variably. Their investments in the electrification of heating, mobility and other equipment are key to reduce the consumption of fossil fuels and increase the use of wind and solar energy among others. Following that, this electrification opens the door to a more managed and flexible demand, which is a potentially important source of decarbonized flexibility provider needed to help balance the electricity system.

4.1.3 Application of DSM

The aim of using DSM is to influence the pattern of electricity consumption that can be useful to achieve selected objectives (Gellings 1985). There can be one or multiple objectives, ranging from helping with system operation (e.g. reduce peak demand, conserve energy resources, and improve system reliability) to improving utility performance (e.g. increase revenues, reduce emissions). The defined objective(s) are then translated into desired demand-pattern changes, which can illustrate the potential changes by implementing a specific DSM programme. Table 3 shows the six types of demand-pattern changes, including peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape.

Load-shape change	Description
	Peak clipping – or the reduction of the system peak loads, embodies one of the classic forms of load management and is now commonly referred to as demand response. Peak clipping is generally considered as the reduction of peak load by using time-based rate options or incentive-based strategies, with or without enabling technologies.
	Valley filling encompasses building off-peak loads. Valley filling can be accomplished in several ways, one of the most popular of which displaces loads served by fossil fuels with electric loads that are operated during off-peak periods (e.g., water heating and/or space heating).
	Load shifting involves shifting load from on-peak to off-peak periods. Popular applications include use of storage water heating, storage space heating, coolness storage, and customer load shifting.
	Strategic conservation is the load-shape change that results from programs directed at end-use consumption. Not normally considered load management, the change reflects a modification of the load shape involving a reduction in consumption as well as a change in the pattern of use.
	Strategic load growth is the load-shape change that refers to a general increase in sales. Load growth may involve increased market share of loads that are or can be, served by competing fuels, as well as economic development. Load growth may include electrification of sectors that were previously fossil-fuel based such as transport and heating.
	Flexible load shape is a concept related to electric system reliability. Load shape can be flexible if consumers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives. The program involved can be variations of interruptible or curtailable load; concepts of pooled, integrated energy

	management systems; or individual customer load control devices offering service constraints.

Table 3 Six types of demand-pattern changes

Source: Adapted from Gellings and Parmenter (2017), Figure 13.3

The implementation of DSM can bring several benefits to the power system operation. For example, Strbac (2008) discussed the benefits in implementing DSM in the UK. Main benefits include the deferment or complete avoidance of investment on new generation capacity (mainly gas units) or investment on new grid infrastructure. Moreover, benefits included relieving congestion in distribution networks and reduction of CO_2 emissions. The study also reviewed major techniques in providing DSM, including

- Night-time heating with load switching
- Direct load control
- Load limiters
- Commercial/industrial programmes
- Frequency regulation
- Time-of-use pricing
- Demand bidding
- Smart metering and appliances

UEA has been actively seeking to provide flexibility services to the power system, using demand-side measures. For example, it provided frequency control services to the grid by using the Dynamic Demand system. A more recently implemented demand-side measure is the experiment on smart heating. In the following sections, we first introduce the concept of demand side management, types and applications of DSM, before introducing demand-side measures adopted at UEA campus.

4.2 Smart heating retrofit

Heating accounts for over half of the total energy consumption at UEA. Annual heat consumption has been stable during the last five years, with only a slight increase from 31.3 GWh in 2016/17 to 33.8 GWh in 2020/21, despite a significant decline in 2019/2020 due to COVID-19 lockdown. Most of the heat was consumed in academic building, which account for approximately two-thirds of the total heat consumption. The rest was consumed at residential buildings.

There are 15 residential buildings at UEA. The top five heat consumers, including Norfolk terrace, Suffolk terrace, INTO, Britten and Crome court represent 58% of the total heating consumption by residential buildings. There are significant variations in terms of heat consumption per bed, which shows a potential energy saving opportunity through energy efficiency improvement. For example, in 2020/21, the least energy efficient building was Crome court building at 3,114 kWh per bed, comparing to the most energy efficient one of Colman building at 1,340 kWh per bed. In general, heat consumption per bed has been declining in all residential buildings during the last five years.

As mentioned in Section 2, the University has adopted several low-carbon technologies to improve energy efficiency and reduce environmental impacts for its energy supply. In spite of major infrastructural changes, significant amounts of energy continue to be wasted in the residential buildings of the UEA campus (>20%), whilst occupant thermal comfort remains problematic. The "invisibility" of energy use and the lack of occupant control over heating temperatures in UEA's dormitories, continue to prevent energy-efficient behaviours and undermine experienced levels of comfort.

Through the development of a smart heating system and through the provision of relevant energy use feedback, we aim to: (a) increase people's awareness of their energy consumption, (b) improve efficiency and allow for system flexibility and (c) optimise control of heating to maximize indoor comfort and even predict, in the near future, building behaviour and energy consumption towards improved automation further flexibility for low carbon energy technologies.

4.2.1 System design

The smart heating system designed and developed within residential buildings on the UEA campus includes 6 key components, including hardware, software and network components (see Figure 12 for a simplified schematic representation of the system):

1. A *zoning control system* that enables the independent operation of heating in individual student room (previously managed centrally at the flat level).
2. *Programmable Thermostatic Radiator Valves (PTRVs)* installed in individual rooms. These are battery-operated and have motorised valves and temperature sensors to control the flow of hot water to the radiators according to a target temperature schedule assigned for the room where the radiator is located. (NB – In contrast to conventional TRVs that are only adjustable to 5-6 different levels and, thus, leave users without a clear understanding of what temperature each level is representing, exact temperatures can be adjusted using these PTRVs).
3. A *central controller* which communicates wirelessly with the PTRVs and through which the schedules for the target temperatures can be set remotely. (NB – Temperature settings can be manually overridden by the occupants if/when needed).
4. *Sensors* for monitoring the outdoor conditions and indoor (ambient) temperature – connected, through *actuators*, to the heating units/system to control their operation based on instructions received by the control algorithm. These enable on/off automatic control of heating units based on: (a) the outdoor weather conditions, (b) indoor temperature, and/or (c) whether windows are open (i.e. function that switches the radiator valve when ventilating the room).
5. A *wireless user interface* allowing users to set up and plan the heating profiles/ set-point temperatures and receive feedback about outdoor and indoor conditions and energy consumption. Up to six set points per day and three different set point temperatures can be set, and users can also choose from three pre-set operation modes – namely 'Eco', 'Holiday' and 'Day-Off' modes depending on their occupancy and specific needs.

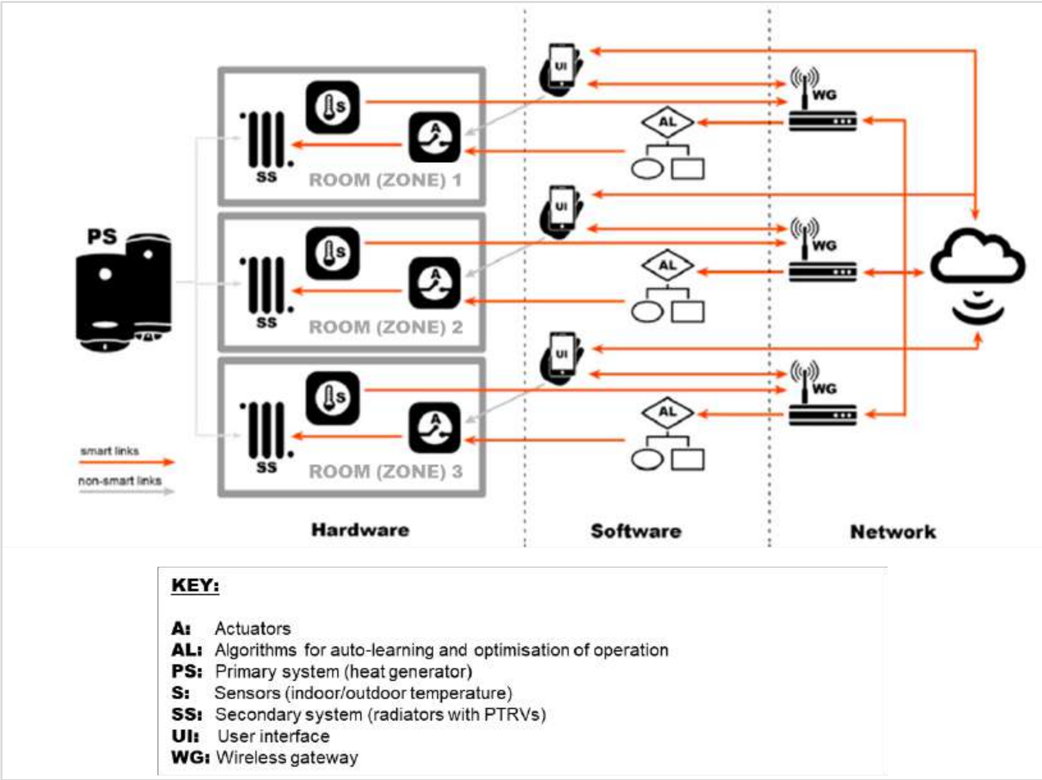


Figure 12: Schematic representation of all the components and connections of the smart heating system designed and delivered in multi-zonal residential units on the UEA campus. (NB – Whilst student flats at the UEA typically comprise of 8-10 individual rooms, the diagram includes only 3 rooms/zones in the interest of simplicity.)

4.2.2 Implemented solution

Smart heating systems – and smart energy technologies in general – are widely celebrated as technological fixes for low carbon energy transition. The specific pilot system at the UEA was expected to allow experimentation and demonstration of such technology. Moreover, a number of benefits were expected to arise because this otherwise simple retrofit radically reconceptualises heating in student dormitories. Specifically:

1. This system offers a cost-effective way of attaining the optimal control of heating. A retrofit intervention with a smart system does not require the replacement of the primary system itself, as its individual components are designed to be easily connected to existing systems wirelessly.

2. The system allows for the partitioning of residential buildings into independent heating zones. By enabling control of heating in each zone (room) following specific user needs and habits in place of depending on central heating control, occupant comfort and convenience are expected to improve.

3. In its real-time optimization, the system considers information regarding outdoor conditions, the occupant presence, the current indoor temperature and the desired comfort temperature to enable efficient energy use without compromising comfort.

4. User interfaces provide an effective and simple way of managing the system according to personalised comfort preferences while being aware of the effect that occupant actions cause to the

system performance. Therefore, one of the most important parameters of system performance ie the users' behaviour, can be studied (see Deliverable 5.1.1).

5. User interfaces enable the comparison of a single user profile with that of other similar users and, thus, offer an opportunity to develop an understanding of energy-related needs and practices on the UEA campus.

Challenges in implementing the smart energy system

The system's ability to deliver on its key aims (namely to increase people's awareness of energy consumption, maximise efficiency, and optimise control of heating) might, ultimately, be undermined by 4 key technological and social challenges:

1. Given that residential buildings at the UEA campus are centrally metered, reliance on clamp-on meters recording energy use (gas flow meters) at the room (in place of the flat or building) level means that data quality can be compromised.
   - The distribution of flow velocity becomes irregular due to bends in the piping or changes in the pipe diameter. Drifting occurs when the centre of the distribution of flow velocity shifts away from the centre of the pipe. Swirl flow occurs when the fluid rotates around a centre axis, parallel to the direction of flow. Both swirling and drifting cause irregular distributions of flow velocity. Performing flow measurements in these conditions may lead to errors.

2. Similarly, proximity of indoor temperature sensors to heat sources might result in imprecise temperature measurements and, consequently, in suboptimal control.

3. The PTVRs are battery powered requiring a battery change on a yearly basis (on average). While, given the very small scale of UEA's pilot study, that has not been a problem, in large-scale rollout of the technologies across university campuses, management/maintenance might prove challenging.

4. Most importantly, the effectiveness of the system in reducing energy consumption whilst improving occupant comfort ultimately depends on the use of the system by the occupants. If occupants reject or misuse the system, the UEA will not be able to realise all of the benefits associated with more efficient energy use.
   - In spite of important automations (e.g. auto-window off function), occupants might: (a) choose to re-set the set-point temperatures to higher points – thus consuming more energy, (b) disable functions, and/or (c) fail to activate energy saving modes when they are off-campus.
   - Given that students living on the UEA campus do not pay for their energy bills, there are no real economic incentives for them to put the technologies to good use by better managing/reducing their energy use.

4.2.3 Integration of the smart heating system into the existing and future low carbon energy systems at UEA

The installation and operation of the smart heating system can be an important element to the overall low carbon energy transition at UEA. There are a few reasons:

a) It can strengthen the user-oriented low carbon solutions at UEA.

User engagement is considered as a cost-effective way to reduce energy consumption. As mentioned in Section 2, there are several activities implemented at the UEA aiming at improving energy performance from the user's perspectives. Several smaller scale activities were implemented, which exemplified the user-oriented approach adopted in the energy strategy by the Estate Service team at UEA. For instance, in a 'great weekend switch off campaign', the Estate team engaged with staff working at the Teaching Wall (UEA's name for a large part of its teaching rooms) in order to remind them to switch off their computers and other equipment during a weekend and other public holiday opportunities. The campaign led to a saving of 10,000 kWh in electricity and £11,000 in cost during a 6-hour power off at the building. Accumulator effects can be expected if similar activities were implemented in other buildings. In addition, the Estates consulted users during the LED upgrade projects. Before making a decision on how to proceed with the upgrade, they talked to users with regard to their experiences on lighting (e.g. rooms were too dark or too light, lighting control ease of use, etc.).

The installation and operation of the smart heating system can strengthen the existing user-oriented approach by extending the user group to students. The project includes several engagement activities with students through focus groups, surveys and interviews. Deliverable 5.1.1 introduces the customer engagement activities in this project in detail. It includes evaluation of students' attitudes towards energy, assessment of their consumption behaviour, consultation on their opinions about the smart heating technologies, and demonstration of the technologies. Students were well-informed about the adopted technology, their means to be involved, and possible outcomes from their participation.

b) It fits the existing low carbon energy systems and can contribute to the future low carbon development plan through flexible management of heating consumption at residential buildings.

Heat consumption at residential buildings represents one-third of the total heat consumption at UEA. At present, heating supply relies on CHP units and gas boilers for production and thermal storage system for storage. Supply side solutions can be better utilised in an integrated approach through a better management of heat demand. It can effectively reduce heat consumption, thus reducing reliance on fossil fuels in the near future.

The University has plans to increase electricity imports due to accelerated decarbonisation of power supply from the grid. Together with the proposed closure of CHP units, there are also plans to switch to heat pumps for heat supply on campus. The replacement in technology as well as the switch to electricity for heat supply will inevitably lead to higher electricity consumption from the grid. As discussed in Deliverable 3.1, electricity consumption in peak hours is considerably more costly than that of off-peak hours. That reflects the use of expensive fossil fuels to generate electricity when demand is very high. Typically, costs are lower when demand is covered by mostly low cost and low carbon energy technologies. If heat consumption could be better managed through the adoption of a scaled up smart heating system, it can be helpful to reduce electricity bills and most importantly consume energy when that is produced by low carbon energy technologies.

c) It provides new opportunities for energy efficiency improvement

Despite a gradual decline in heat consumption at residential buildings, there are significant variations in the heat consumption per bed at different residential buildings. A number of measures have been adopted to improve the energy performance in residential buildings, including room retrofitting, double glazing, and so on. There are still opportunities to further energy efficiency improvement.

The smart heating system offers a novel approach to reduce emissions by improving energy efficiency through user engagement. The more granular control over heating at different time periods and with more precise temperature settings offer an effective means to increase savings in heat demand. One other important element from user participation is that it can improve the user awareness on issues related to climate change in general and transition in energy provision in particular. These are fundamental to the successful implementation of the Net Zero plan at UEA as well as the low carbon energy transition at national level.

d) It offers a cost-effective means to reduce energy consumption and emissions

UEA has implemented a series of investments to reduce its energy consumption including LED upgrade as well as replacement of old and inefficient equipment. These projects were relatively small in cost but presented good opportunities for energy savings and emission reduction. For example, the University has initiated 17 small projects aiming at energy efficiency improvement at UEA campus between 2016 and 2020 under the SALIC funding scheme. Three main activities were sponsored, including lighting upgrade (6 projects), building insulation (2 projects), and equipment replacement (9 projects). Total investment was £523,432. It led to annual savings in electricity consumption in 1,893 MWh and associated annual savings in cost (£184,447) and CO_2 emissions (540 tonnes). The projects had an average payback period of 2.8 years, ranging between 0.4 and 6.9 years. 15 out of the 17 projects showed energy savings by more than 50%; while 3 projects experienced over 90% reduction in energy consumption. One key project was related to the SCVA building LED upgrade with total investment of £154, 352. Total electricity consumption decreased from 503,224 kWh to 51,164 kWh per year. Annual cost savings are £55,355, which result in a payback period of 2.8 years.

Similar to the SALIC projects, potential scaling up of the smart heating system also offers a cost-effective way to reduce heating consumption at residential buildings. The smart heating system does not require significant spending on equipment. Its operation and maintenance costs are negligible.

4.2.4 Results of implementing the smart heating system

This subsection shows the performance of the smart heating system in general and its impact on gas consumption at UEA dormitories. More detailed analysis can be found in Deliverable 5.1.1.

Figures 13 and 14 below compare the weekly gas consumption by students participating in the smart heating system experiment (Living Lab) and by students who did not participate in the experiment (Control flat). There are two experiments conducted at two different buildings (UEA Village Courtyard A and UEA Village Courtyard B). Similar consumption patterns can be observed in the two case studies. It shows that after an initial period of familiarity with the system, students started to actively engage with the system. It led to significant savings in gas consumption. However, students reverted to more energy-demanding heating behaviours after around 14 weeks of residing in the Living Lab.

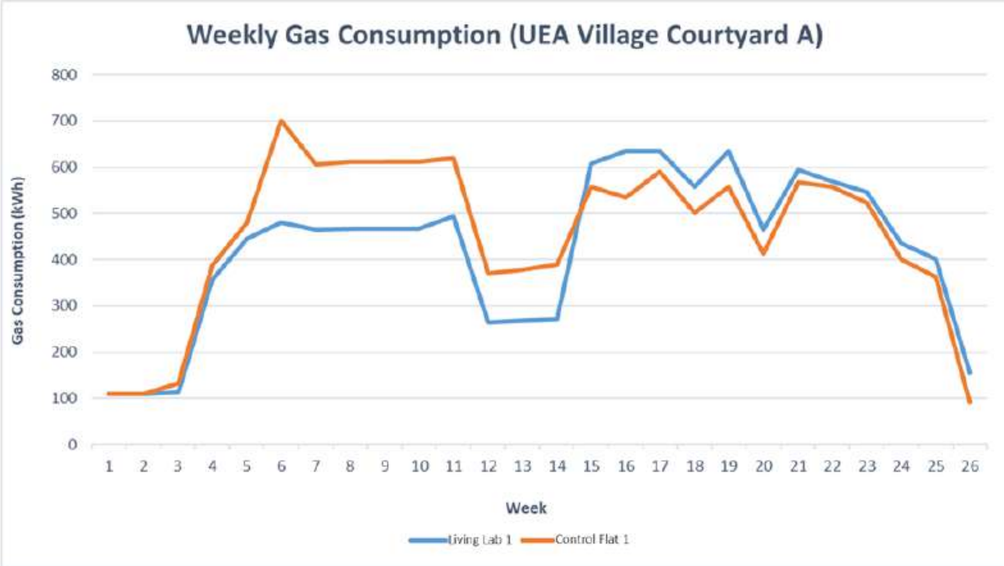


Figure 13: Weekly gas consumption (heating) in Living Lab and Control Flats 1 (UEA Village, Courtyard A). NB: Dip in energy use between weeks 12 and 14 (for both flats) is attributed to the winter holiday period when the majority of students were away from their rooms on campus for several days/ weeks.

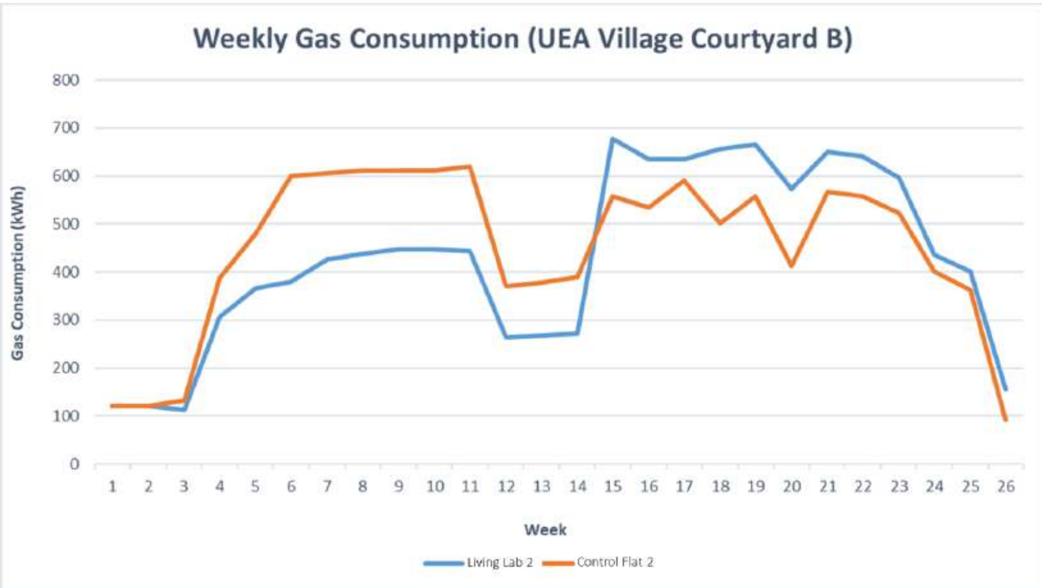


Figure 14: Weekly gas consumption (heating) in Living Lab and Control Flats 2 (UEA Village, Courtyard B). NB: Dip in energy use between weeks 12 and 14 (in both flats) is attributed to the winter holiday period when the majority of students were away from their rooms on campus for several days/ weeks.

Nevertheless, the implementation of the smart heating system led to savings in gas consumption over a period of 26 weeks (See Figure 15). Better communication strategy, more intuitive settings can facilitate the higher level of participation in the future. Deliverable 5.1.1 provides detailed discussions on the solutions.

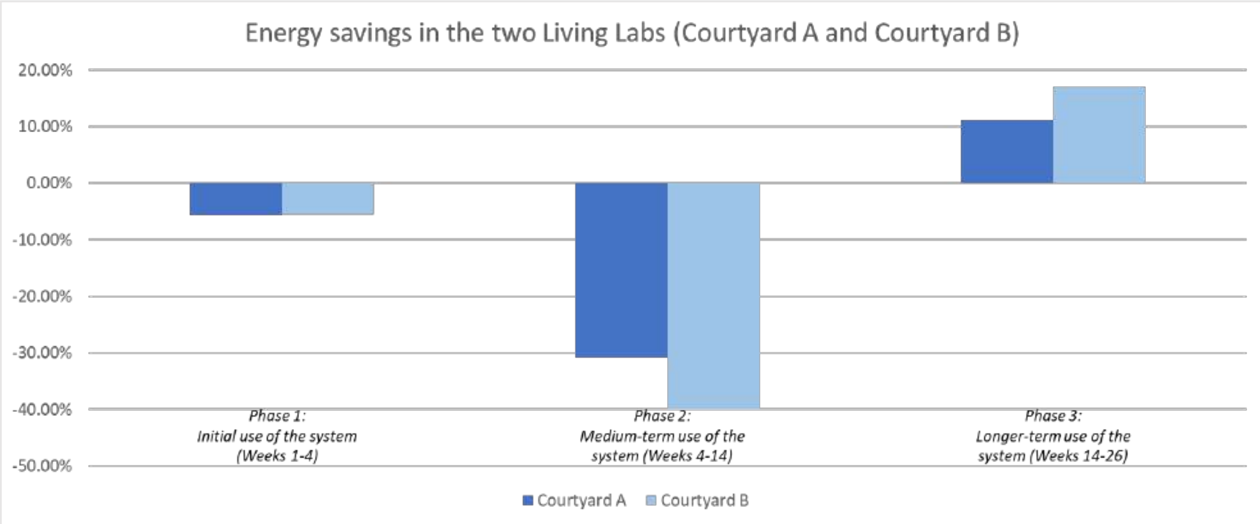


Figure 15: Energy savings in UEA's two Living Labs (compared against control flats in Courtyard A and Courtyard B respectively)

4.3 Frequency response

4.3.1 Frequency response – a description

Electrical system frequency is a continuously changing variable that is determined and controlled by the second-by-second (real time) balance between system demand and total generation (National Grid ESO 2021b). If changes in demand cannot be matched by generation, there will be falls and increases in system frequency. It is important to maintain system frequency at a standard level (e.g. 50Hz in Great Britain or 60Hz in the United States). Deviations above 1% from the standard frequency level (either higher and lower) can lead to electrical system instability and damage to equipment and infrastructure. The National Grid ESO manages the system frequency in the UK. They are responsible for giving instructions to power generators to respond to changes in frequency. For example, when frequency falls, power generators increase their power output; when frequency rises, power generators reduce their power output.

Traditionally, thermal power generators can provide frequency response at scale. Typically, this is done with open cycle gas turbines due to their capability of ramping up and down production in a relatively short period of time (some in seconds) as well as remain at the output level for a given period of time (minutes or even hours). The closure of fossil fuel-based plants and the deployment of renewables have reduced the capability of providing supply-side frequency response. At the same time renewables introduce higher demand for frequency response since they generate power at variable output. Therefore, new forms of frequency response have been identified, including the use of energy storage systems as well as demand response (Drax 2017). Frequency response is procured by the National Grid through a mixture of weekly and monthly auctions. Providers can range from power generators, storage systems and aggregated demand-side response. Therefore, the idea is that to balance the frequency an intervention needs to increase or reduce supply or demand. A power generator can increase supply; a storage system, can either increase supply (by discharging its stored energy into the grid) or increase demand (by charging itself) and; an aggregated demand-side system can reduce or increase demand by switching on or switching off certain energy consumption activities. If the aggregated demand-side system is additionally connected to a battery (energy storage) then it can perform all of the aforementioned roles.

There are three response speed classifications for frequency response in the UK system (See Table 4 below). Providers can offer one or a combination of different response times depending on the capability (response speed) of their technology.

	Speeds of response	**Sustained periods**
Primary response	Within 10 seconds of an event	For a further 20 seconds
Secondary response	Within 30 seconds of an event	For a further 30 minutes
High frequency response	Within 10 seconds of an event	Indefinitely.

Table 4 Three response speeds for frequency response

Source: (National Grid ESO 2021a)

Previous studies found that the provision of frequency response from demand-side response can greatly reduce system operation cost, alleviate renewable energy curtailment, and reduce CO_2 emissions (Aunedi et al. 2013, Teng et al. 2015).

4.3.2 Frequency response at UEA

UEA has committed to reduce the environmental impacts of its energy consumption activities. One of the significant activities is the adoption of a dynamic approach in its energy demand management. With the installation of the Dynamic Demand (DD) system operated by OpenEnergi, UEA could provide frequency response by adjusting the electricity consumption through the air handling units (AHU) at buildings (See Figure 16).

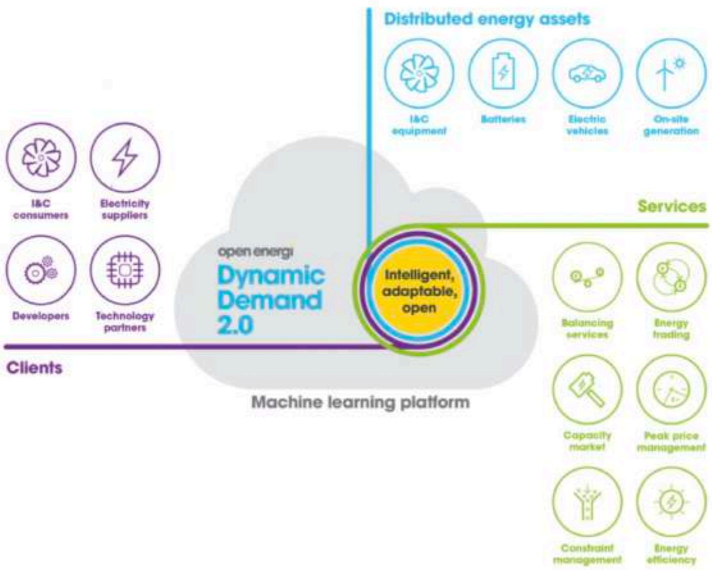


Figure 16 Dynamic demand system by Open Energi

Source: (Open Energi 2021)

The DD system is built into the building management system that can be found in virtually all types of large buildings. Energy use can be controlled automatically in response to the system needs of frequency control. A range of energy use activities can participate in its operation, including heating, cooling and water pumping. It is believed that the DD system has a massive market potential since the non-residential buildings account for 300 TWh of energy consumption each year.

Through the aggregation of distributed energy assets, the dynamic demand system provides a platform that optimises the system operation and creates a pool of flexible demand sources. Such flexibility can provide a series of grid services, such as balancing services, peak demand management, congestion alleviation, and energy efficiency improvement. In the UK, demand flexibility has been growing fast as it facilitates the integration of renewable energy sources and reduces system costs. A more flexible energy system could save the UK up to £8 billion a year by 2030, and up to £16 billion a year by 2050 (Committee on Climate Change 2019). On the other hand, the users can benefit from reduced energy bills (e.g., through reduced charges during peak hours) and improved energy performances, therefore creating a more sustainable energy system.

The platform is developed based on data-driven insight and advanced technology. It is part of the decentralised energy solutions that allow the integration of various distributed energy resources (DERs), such as CHP, DSR, and energy efficiency measures. Decentralised energy plays a significant role in the energy transition that, since

- Most of the decentralised energy sources have zero or close to zero emissions during their operation, such as wind, solar, biomass and geothermal.
- DERs are more efficient as they can provide multiple energy services at the same time. Since DERs are usually close to users, they can also reduce transmission and distribution (T&D) losses.
- DERs can improve the reliability of local grid.
- DERs can reduce overall system costs through avoided costs in grid infrastructure and power generation units.

UEA is the first university to install such a system across its campus. The adjustment in energy use can be made by turning on and off its air handling units (AHU) through the air control equipment in each building if National Grid experiences a surge in demand or a decline in supply. Total participating load is around 700kW through a combination of air handling units and chillers. The AHUs are controlled for a short period of time (a few minutes). Therefore, the level of user comfort is not impacted during the period when AHUs are in operation.

The activity can happen very quickly which can help the grid operator to maintain system frequency at 50 Hertz. Martyn Newton, Assistant Director of UEA Estates - Risk and Sustainability said that *"Open Energi's technology provides a cleaner and more efficient answer to balancing the grid than ramping a power station output up and down. We provide access to our loads within strictly controlled boundaries and in return we get paid."*

There are multiple benefits of providing frequency response services. For instance, there was a revenue stream of up to £50,000 pounds per year over three years between 2014 and 2017. It also helped to reduce the UEA's carbon footprint due to reduced energy consumption. Indeed, building related emissions accounted for 99% of the carbon reduction target, mainly through electricity and heat use. The provision of frequency response through AHTs in buildings represented a step-forward to reduce building related emissions at UEA. In addition, frequency response services are necessary if the campus were to operate in island mode. While operated in island mode, the system must balance supply and demand in real time. Conventional supply side technologies such as CHP plant used to making adjustment to match changes in demand. However, the integration of renewable energy sources has made the supply side less flexible in providing these services. Therefore, the frequency response services provided by the AHTs at UEA offer an important decarbonised alternative to manage system frequency when operated in island mode.

4.4 Other interventions implemented and considered at UEA

Apart from the implemented interventions above, the UEA also considered other measures to reduce its energy consumption and associated CO_2 emissions. For example, UEA participated in the capacity market and considered the provision of short-term operating reserves between 2017 and 2019, using its low carbon energy technologies. This subsection includes a general introduction of the two services and an explanation on the benefits of providing these services at UEA.

Capacity market

The general theoretical arguments in favour of capacity markets reflect scepticism about whether competitive energy-only markets will deliver high quality power, at affordable price with minimal or even zero emissions. Even more so that this has to happen in a way that will allow recovery of the fixed costs of investment.

To deal with the resource adequacy concern, the UK initially used a Contingency Balance Reserve (CBR), managed by National Grid Company (NGC), provide additional reserve in the mid-decade period. This reserve was a transitional product and 2016 was the last year it was in use. It was replaced by a capacity market for Great Britain (GB) to address concerns about resource adequacy. The GB capacity market is organized as a (descending) auction which includes all technologies that do not receive subsidies, with all winners receiving the marginal price for the period of their contract, usually one year. The capacity auctions are held when the government considers that there is a need; four years before delivery (T-4) and 1 year before delivery (T-1). Until this year, capacity markets were clearing at well below £20/kW/year, reflecting a healthy reserve margin, as illustrated in Figure 17. There were two particularly notable developments. One was the decline in the share of capacity agreements awarded to existing power stations, including coal, nuclear and CCGT plants. The other was the increasing importance of capacity awards for technology options such as Open Cycle Gas Turbines, Renewable Generation, Interconnectors and Demand-Side Response.

Figure 17 UK T-4 Capacity market clearing prices

Source: (Cornwall Insight 2021)

In 2017, UEA signed a contract with KiWi Power for the provision of services in respect of the Capacity Market between October 2018 and September 2019. UEA agreed to make capacity available to KiWi Power in respect of T-1 Existing Generation. The capacity available will be used to reduce stress on the grid during times of peak demand. It was required to provide full service within 4 hours of instruction and deliver for the duration of event (up to 4 hours). Expected annual revenues from participating capacity market was £6,950 per MW.

STOR – Short Term Operating Reserve

Power system operation requires real-time balance between supply and demand. Traditionally, supply is adjusted upwards or downwards to meet the change in demand that is largely predictable. On occasions, actual demand is higher than predicted demand, short term operating reserve is needed through either increasing generation or reducing demand. STOR is part of the overall balancing services in the UK. The STOR service can be provided by a single supply/demand unit or in an aggregated form which includes more than one site. Its most recent technical requirements include:

- A minimum of 3 MW of generation or equivalent steady demand reduction.
- A response time within 20 minutes.
- A minimum response duration of 2 hours.
- Within 1,200 minutes (20 hours) of recovery, can provide response again.

UEA considered the provision of STOR service through collaborations with an energy service company in 2017. Expected annual income amounted to £25,000 per available MW. The expected revenue comes from availability and utilisation payments. UEA needs to provide services in up to 10 events per year. The expected duration of each event is 2 hours with a minimum 20-minute notice of events.

4.5 Conclusions

The transition away from fossil fuels and increasing penetration of renewable energy sources have led to changing structure in supply and subsequently the ability of providing flexible services from the supply side to the power system. Alternative sources need to be drawn from the demand-side, which has been largely overlooked in the traditional power system operation.

The ICE project has initiated the pilot of a cost-effective approach to managing energy consumption at UEA campus. The smart heating system includes components that enable the optimal use of heating, including programmable thermostatic radiator valves, zoning control systems, central controllers, and wireless interface. Such technological solutions do not require replacement of the existing system, but to retrofit the existing system with more interactive functions with its users. Multiple user engagement activities were held to gather user experiences, which are vital to the success of the technological solutions.

Another key aspect in the demand-side solution at UEA is the adoption of frequency response. Through the control of AHUs in academic buildings, power demand in these buildings is reduced for a short period of them. Without compromising the user comfort, it provides frequency services to the National Grid. Such services can be useful for the UEA when its power system operates in island mode.

Indeed, the scaled implementation of the smart heating system may provide a significant opportunity for the UEA to better explore the potential in providing FR services in the future. Similar to the control of AHUs in academic buildings, the smart heating system can better manage heating consumption at different time scales (e.g. through more granular configurations on time of use). Without compromising user comfort, the smart heating system can be helpful to manage demand, which can be a significant demand-side source when operated in an aggregated manner. Such arrangement may even become necessary when heating is electrified through the adoption of heat pumps in the future. New opportunities will also emerge since the power system will require higher level of flexibility that will make detailed consideration of electric energy storage more topical (Li et al. 2018, Li et al. 2019).

4.6 References

Aunedi, M., P. Kountouriotis, J. E. O. Calderon, D. Angeli and G. Strbac (2013). "Economic and Environmental Benefits of Dynamic Demand in Providing Frequency Regulation." IEEE Transactions on Smart Grid **4**(4): 2036-2048.
Behrangrad, M. (2015). "A review of demand side management business models in the electricity market." Renewable and Sustainable Energy Reviews **47**: 270-283.
BEIS (2020). UK energy in brief 2020, Department for Business, Energy & Industrial Strategy
Chandler, H. (2011). Harnessing Variable Renewables: A Guide to the Balancing Challenge, International Energy Agency.

Committee on Climate Change (2019). Net Zero - Technical Annex Integrating variable renewables into the UK electricity system.
Cornwall Insight (2021). Energy Spectrum. **Issue 754**.
Drax. (2017). "Why we need the whole country on the same frequecny." Retrieved 23 July, 2021, from https://www.drax.com/power-generation/need-whole-country-frequency/.
Drax (2020). Electric Insights Quarterly: Q2 2020.
Eto, J. (1996). The Past, Present, and Future of U.S. Utility Demand-Side Management Programs. Berkeley, California, Lawrence Berkeley National Laboratory.
Ganandran, G. S. B., T. M. I. Mahlia, H. C. Ong, B. Rismanchi and W. T. Chong (2014). "Cost-benefit analysis and emission reduction of energy efficient lighting at the Universiti Tenaga Nasional." TheScientificWorldJournal **2014**: 745894-745894.
Gelazanskas, L. and K. A. A. Gamage (2014). "Demand side management in smart grid: A review and proposals for future direction." Sustainable Cities and Society **11**: 22-30.
Gellings, C. W. (1985). "The concept of demand-side management for electric utilities." Proceedings of the IEEE **73**(10): 1468-1470.
Gellings, C. W. and K. Parmenter (2017). Demand-Side Management. Energy Management and Conservation Handbook. F. Kreith and D. Goswami. Boca Raton,, CRC Press, Taylor & Francis Group.
Grubb, M. and D. Newbery (2018). UK Electricity Market Reform and the Energy Transition: Emerging Lessons. EPRG Working Paper 1817, University of Cambridge, Energy Policy Research Group.
Kamat, A. S., R. Khosla and V. Narayanamurti (2020). "Illuminating homes with LEDs in India: Rapid market creation towards low-carbon technology transition in a developing country." Energy Research & Social Science **66**: 101488.
Li, X., K. J. Chalvatzis and P. Stephanides (2018). "Innovative Energy Islands: Life-Cycle Cost-Benefit Analysis for Battery Energy Storage." Sustainability **10**(10): 3371.
Li, X., K. J. Chalvatzis, P. Stephanides, C. Papapostolou, E. Kondyli, K. Kaldellis and D. Zafirakis (2019). "Bringing innovation to market: business models for battery storage." Energy Procedia **159**: 327-332.
National Grid ESO. (2021a). "Firm frequency response (FFR)." Retrieved 23 July, 2021, from https://www.nationalgrideso.com/industry-information/balancing-services/frequency-response-services/firm-frequency-response-ffr.
National Grid ESO. (2021b). "Frequency response services." Retrieved 23 July, 2021, from https://www.nationalgrideso.com/industry-information/balancing-services/frequency-response-services.
Open Energi. (2021). "Dynamic Demand 2.0." Retrieved 23 July, 2021, from https://openenergi.com/technology.
Pollitt, M., C. Yang and H. Chen (2017). Reforming the Chinese Electricity Supply Sector: Lessons from International Experience
Strbac, G. (2008). "Demand side management: Benefits and challenges." Energy Policy **36**(12): 4419-4426.
Teng, F., M. Aunedi, D. Pudjianto and G. Strbac (2015). "Benefits of Demand-Side Response in Providing Frequency Response Service in the Future GB Power System." Frontiers in Energy Research **3**: 36.

5 Mutual Learning between UEA and Ushant

Mutual learning and capacity building are also key elements in this deliverable. The lessons learnt at UEA can provide knowledge about smart grid applications to Ushant; while the Ushant application can offer valuable insights to UEA on its island mode grid operation. This section introduces key takeaways from both cases studies and discusses possibility of transferable outcomes between each other.

5.1 Transferable outcomes from Ushant

Ushant as a non-interconnected island faces energy supply security challenges (Ioannidis and Chalvatzis 2017, Ioannidis et al. 2019). While these challenges are not limited to energy supply but can extend to polluting emissions, they can also be addressed by technological and organisational means (Spyropoulos et al. 2005, Hills et al. 2018). Ushant has demonstrated the adoption of smart technologies that can better manage energy consumption in order to achieve an island mode grid operation. These technologies include the application of an energy management system (EMS), the operation of a tidal turbine with a battery storage system, the adoption of smart meters and automation system.

An EMS is used to maintain system stability while maximising the integration of renewable energy sources at Ushant. Multiple energy technologies can be integrated into the system, including conventional thermal power plants, storage systems, demand-side resources as well as renewable energy technologies, which are closely monitored by the EMS. One of the key components managed by the EMS is a Lithium-ion battery storage system. Electricity produced by various renewable technologies can be stored in the battery system when there is excessive generation. The battery can be discharged when generation is low. It is especially useful to manage electricity generation from tidal turbines which usually have variable outputs at different timescales. The battery system is utilised as a flexible source to smooth the power outputs. The combination of battery energy storage and renewables can be applied to many times of facilities (including the UEA campus), or even industrial sites (Zafirakis et al. 2014) and it can provide power quality without the use of fossil fuels that other technology combinations require (Zafirakis and Chalvatzis 2014). Ushant has also included demand-side measures to manage the power system. For example, it has adopted Time-of-use (ToU) tariff to shift consumption from peak to off peak hours. The installation of smart meters allows for further disaggregation of off-peak hours, which avoids a surge in demand when off-peak hour begins. The system also proposes a renewable energy generation tracked tariff that allows the coordination between tidal power generation and consumption. Signals will be sent once tidal turbine is in operation. The energy system in Ushant has also included pilots on the automatic control of equipment through smart meters. A central platform is established that can facilitate communications wirelessly between the EMS and various equipment. The aggregated load can provide flexible sources to the power system, which is important to the secure supply of electricity.

Apart from technological solutions, the ICE project includes various consumer engagement activities which are documented for their challenges especially with populations of remote territories (Kallis et al. 2021). Such activities include dissemination of information related to energy consumption, introduction of local energy context, and presentation of home energy management. The project team has provided three types of information that allow different levels of information revealed (from easy to understand, general information to detailed information with graphs and figures). This allows consumers with different levels of willingness to participate in the programme to have relevant information.

Some of the adopted technologies and engagement activities at Ushant are also in operation at the UEA campus. For example, UEA uses energy management systems that coordinate the operation of different technologies, which enable the optimised integration of its low carbon technologies. In addition, UEA also has implemented several user engagement activities (including the engagement activities with students in the ICE project), which are introduced in Section 3.

Nevertheless, the adoption of a battery storage system in combination with the operation of the tidal energy system can be useful to the development of DERs at UEA. Similar concept has been used at the UEA, exemplified by the adoption of CHP and boilers in combination with the thermal storage system. With the on-going expansion of solar PV capacity, UEA has considered the installation of a battery storage system.

One other useful lesson is the application of automation, which allows the control of equipment in a remote manner. UEA has a large number of student accommodations that are not individually metered. Students do not pay for their energy bills, which are often included in their total rent price, therefore lacking motivation to participate in demand-side related programmes from an economic perspective. Data driven automation offers a solution that provides an opportunity to draw on the potential of large-scale participation from students. Also careful consideration needs to be made for large-scale data collection on campus's micro-grid and their intelligent use for high frequency decision making (Chalvatzis et al. 2019).

The University has committed to a net zero carbon emission by 2045. It can have significant implications to the energy strategies at UEA. One notable change to the future plan of UEA's energy provision is the idea of moving away from an independent energy system to a more grid-connected system while retaining the capability to do both within appropriate conditions. While this might offer great security of supply, a whole range of considerations will need to be part of the decision making to ensure that security improvements are deliverable and in balance with other objectives (Vafadarnikjoo et al. 2021). This is due to the recent changes in the power mix at national level, which shows a sharp decline in coal power and a fast growth of renewable energy sources. Despite a significant role of gas in the existing power mix, the UK government has committed to decarbonise electricity by 2035 and past and forthcoming innovation measures will facilitate this approach (Pitelis et al. 2020). Renewable and low carbon technologies such as offshore wind and nuclear energy will play a significant role in the replacement of fossil fuels. In addition, the electrification of heating and mobility can lead to a significant increase in power consumption, nationally and at the UEA campus. Therefore, UEA has plans to increase imports from the grid in the future, a decision that presents several challenges on its own. While the grid is generally decarbonised, a large energy consumer, such as the UEA campus needs to carefully examine the electricity suppliers available and ensure it selects the most appropriate one for their innovations, rather than their branding about sustainability credentials (Rutter et al. 2018). Automation can still be an important solution to UEA's energy system in the future, when most of its heating consumption will be electrified. Similar to the control of AHUs for the provision of FC services, automation technology can draw up a significant flexibility source from the demand side without compromises on user comfort.

5.2 Transferable outcomes from UEA

Section 2 and 3 of this deliverable introduce the low carbon energy adopted at the UEA. The energy system can provide lessons to Ushant on the building of an integrated energy system that optimise the energy performance. Clearly, given the scale differences and the fact that UEA grid connected whereas Ushant is not, not everything is directly applicable.

At first, the upgrade of new energy technologies, even when relying on fossil fuels including new gas units and thermal storage systems can improve overall energy efficiency, if they are replacing old inefficient systems. Apart from the better operating efficiency, the low carbon technologies are integrated with each other. For instance, the CHP plant and gas boilers reach their optimal operating efficiency with the installation of a thermal storage system. The thermal storage system stores excessive heat production for later use through the district heating and cooling systems, therefore an example of better utilisation of resources. The top-down solutions are better coordinated with the bottom-up approaches which draw on effective communication with staff and students. Such engagement activity focuses on the demand side through changing consumption behaviour as well as automated control of heating and cooling services. With no compromise on user comfort, these measures effectively reduce energy consumption and associated environmental impacts. Two examples are mentioned in Section 3, namely the smart heating system at UEA residential buildings and the adoption of the dynamic demand system. Furthermore, one more smart-grid element that can be considered for Ushant and UEA has experience with is the frequency response system. While the main application of frequency response remains to allow services for the grid outside the entity that operates it and therefore it requires grid connectivity, there are useful operations from it even in island mode. Therefore, instead of providing services for the outside grid, provide services for the internal microgrid. France has a relatively low carbon electricity sector, unlike other European countries which have begun their decarbonisation from a very polluting start (Kaldellis et al. 2004, Chalvatzis 2009), and its islands are interesting decarbonisation case studies, unlike other European countries. Essentially, frequency response is a type of demand side management system which if engineered correctly it can deliver rapid response, significantly faster than any other similar technology. As such its services can be valuable at any setting where balancing is required and micro-grids normally have that need.

5.3 Conclusions

The low carbon energy transition at UEA and Ushant can promote mutual learnings. UEA can learn from Ushant on the application of battery storage system in combination with renewable energy technologies. In addition, demand-side measures such as automation can also provide opportunity for more flexible demand-side sources, if the smart heating system demonstration can be expanded to a large number of dormitories in the future at UEA. For Ushant, lessons can be learnt from the building of an integrated energy system that optimise the energy performance at UEA as well as the potential for use of frequency response systems where that is viable.

5.4 References

Chalvatzis, K. J. (2009). "Electricity generation development of Eastern Europe: A carbon technology management case study for Poland." Renewable and Sustainable Energy Reviews **13**(6): 1606-1612.

Chalvatzis, K. J., H. Malekpoor, N. Mishra, F. Lettice and S. Choudhary (2019). "Sustainable resource allocation for power generation: The role of big data in enabling interindustry architectural innovation." Technological Forecasting and Social Change **144**: 381-393.
Hills, J. M., E. Michalena and K. J. Chalvatzis (2018). "Innovative technology in the Pacific: Building resilience for vulnerable communities." Technological Forecasting and Social Change **129**: 16-26.
Ioannidis, A. and K. J. Chalvatzis (2017). "Energy Supply Sustainability For Island Nations: A Study on 8 Global Islands." Energy Procedia **142**: 3028-3034.
Ioannidis, A., K. J. Chalvatzis, X. Li, G. Notton and P. Stephanides (2019). "The case for islands' energy vulnerability: Electricity supply diversity in 44 global islands." Renewable Energy **143**: 440-452.
Kaldellis, J., G. Spyropoulos and K. Chalvatzis (2004). "The Impact of Greek Electricity Generation Sector on the National Air Pollution Problem." Fresenius Environmental Bulletin **13**: 647-656.
Kallis, G., P. Stephanides, E. Bailey, P. Devine-Wright, K. Chalvatzis and I. Bailey (2021). "The challenges of engaging island communities: Lessons on renewable energy from a review of 17 case studies." Energy Research & Social Science **81**: 102257.
Pitelis, A., N. Vasilakos and K. Chalvatzis (2020). "Fostering innovation in renewable energy technologies: Choice of policy instruments and effectiveness." Renewable Energy **151**: 1163-1172.
Rutter, R., K. J. Chalvatzis, S. Roper and F. Lettice (2018). "Branding Instead of Product Innovation: A Study on the Brand Personalities of the UK's Electricity Market." European Management Review **15**(2): 255-272.
Spyropoulos, G., K. Chalvatzis, A. Paliatsos and J. Kaldellis (2005). Sulphur Dioxide Emissions Due to Electricity Generation in the Aegean Islands: Real Threat or Overestimated Danger?
Vafadarnikjoo, A., M. Tavana, K. Chalvatzis and T. Botelho (2021). "A socio-economic and environmental vulnerability assessment model with causal relationships in electric power supply chains." Socio-Economic Planning Sciences: 101156.
Zafirakis, D. and K. J. Chalvatzis (2014). "Wind energy and natural gas-based energy storage to promote energy security and lower emissions in island regions." Fuel **115**: 203-219.
Zafirakis, D., C. Elmasides, D. U. Sauer, M. Leuthold, G. Merei, J. K. Kaldellis, G. Vokas and K. J. Chalvatzis (2014). "The Multiple Role of Energy Storage in the Industrial Sector: Evidence from a Greek Industrial Facility." Energy Procedia **46**: 178-185.

6 Conclusions

UEA has adopted a number of low carbon energy technologies in recent years to improve its environmental and energy performance. From the supply side, UEA invested in solar PV systems, installed and upgraded the gas CHP units, upgraded three gas boilers, and installed a thermal storage system. The applications of low carbon energy technologies have effectively reduced the CO_2 emissions at the UEA campus. In addition, it has resulted in savings in energy cost due to energy efficiency improvements. From the demand side, UEA adopted novel technologies to reduce energy consumption in its buildings, such as the adoption of TermoDeck technology and the upgrade of LED lighting in its academic buildings. The low carbon energy technologies are integrated together to achieve optimal performance, which lead to reduced energy consumption and associated carbon emissions. For example, the CHP plant and gas boilers reach their best operating efficiency through the combination with the thermal energy storage systems. District heating and cooling systems are used to achieve better utilisation of resources. Apart from supply-side solutions, the UEA has been actively engaged with staff and students in order to explore opportunities to further improve energy performance using an energy consumer-oriented approach.

UEA's future energy plan is guided by a commitment of becoming net zero carbon emissions campus by 2045, leading to a transition away from fossil fuels and an increase in renewable energy generation in the future. At national level, these changes have led to changing structure in supply and subsequently the ability of providing flexible services from the supply side to the power system. Similarly, these changes can also have significant impacts on energy provision at UEA. Apart from energy storage systems (such as batteries), alternative sources need to be drawn from the demand-side, which has been largely overlooked in the traditional power system operation.

Though a small-scale demonstration, the ICE project has provided a cost-effective approach to managing energy consumption at UEA campus. The smart heating system includes components that enable the optimal use of heating, including programmable thermostatic radiator valves, zoning control systems, central controllers, and wireless interface. Such technological solutions do not require replacement of the existing infrastructure, but to retrofit the existing system with more interactive functions for its users. Multiple user engagement activities were held to gather user experiences, which are vital to the success of the technological solutions. Another key aspect in the demand-side solution at UEA is the adoption of frequency response. Through the control of AHUs in academic buildings, power demand in these buildings is reduced rapidly but only for a short period. Without compromising user comfort, it provides frequency services to the National Grid. Such services are also necessary for the UEA when its power system operated in island mode.

Indeed, the large-scale implementation of the smart heating system may provide a significant opportunity for UEA to better explore the potential in providing FR services in the future. Similar to the control of AHUs in academic buildings, the smart heating system can better manage heating consumption at different time scales (e.g. through more granular configurations on time of use or through automation technology). Without compromising user comfort, the smart heating system can be helpful to manage demand, which can be a significant demand-side flexibility source when operated in an aggregated manner. Such arrangement may even become necessary when heating is electrified through the adoption of heat pumps in the future. New business opportunities may also emerge since the power system will require higher level of flexibility.

Last but not least, the low carbon energy transition at UEA and Ushant can promote mutual learnings. UEA can learn from Ushant on the application of battery storage system in combination with renewable energy technologies. In addition, demand-side measures such as automation can also provide opportunity for more flexible demand-side sources, if the smart heating system demonstration can be expanded to a large number of dormitories in the future at UEA. For Ushant, lessons can be learnt from the building of an integrated energy system that optimise the energy performance at UEA as well as the potential for use of frequency response systems where that is viable.

Appendix I: The exhibition materials in both French and English

Pour rappel la date du BAT étant fixé au 24 août, merci de signer au plus vite ce BAT.

Tous les logos sont en HD, l'aperçu du pdf donne une version pixellisée qui n'apparaît pas à l'impression.

BAT Exposition mobile

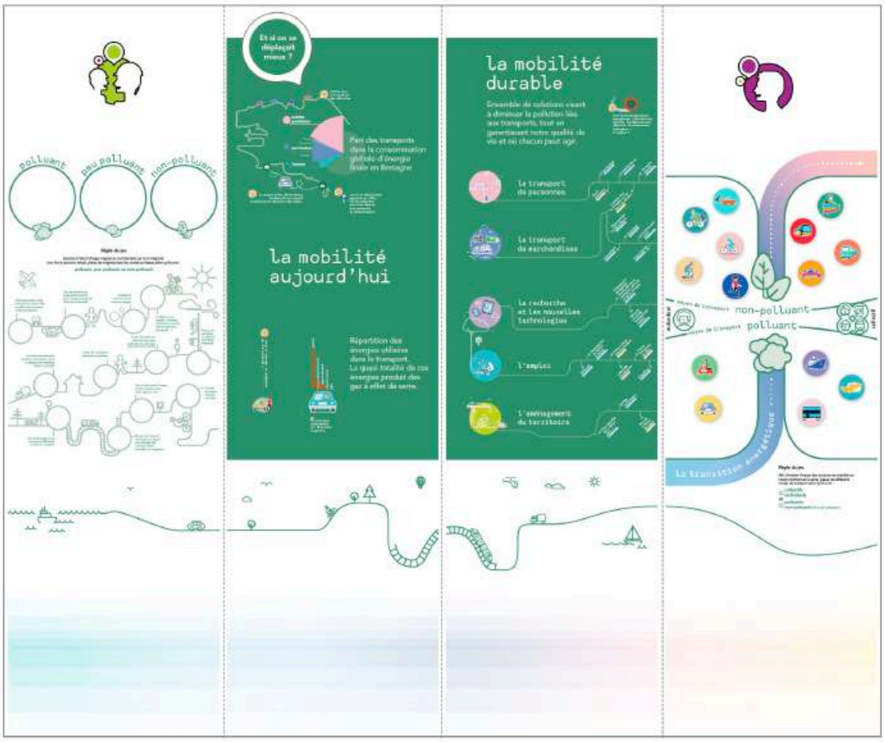
les paravents - français et anglais

V5 - 29 août 2018

introduction - version FR

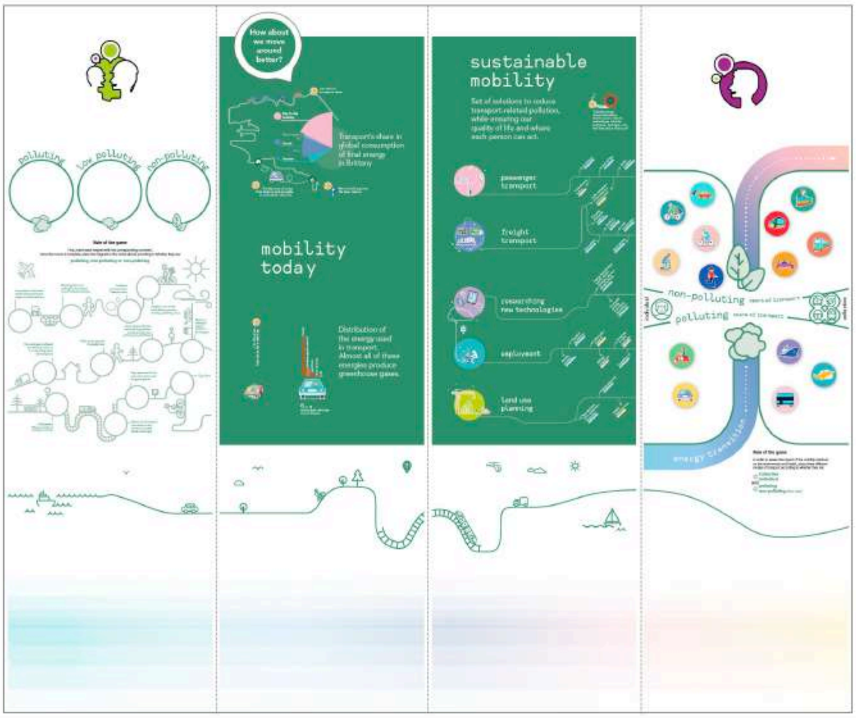
introduction - version EN

mobilité - version FR



4

mobilité - version EN



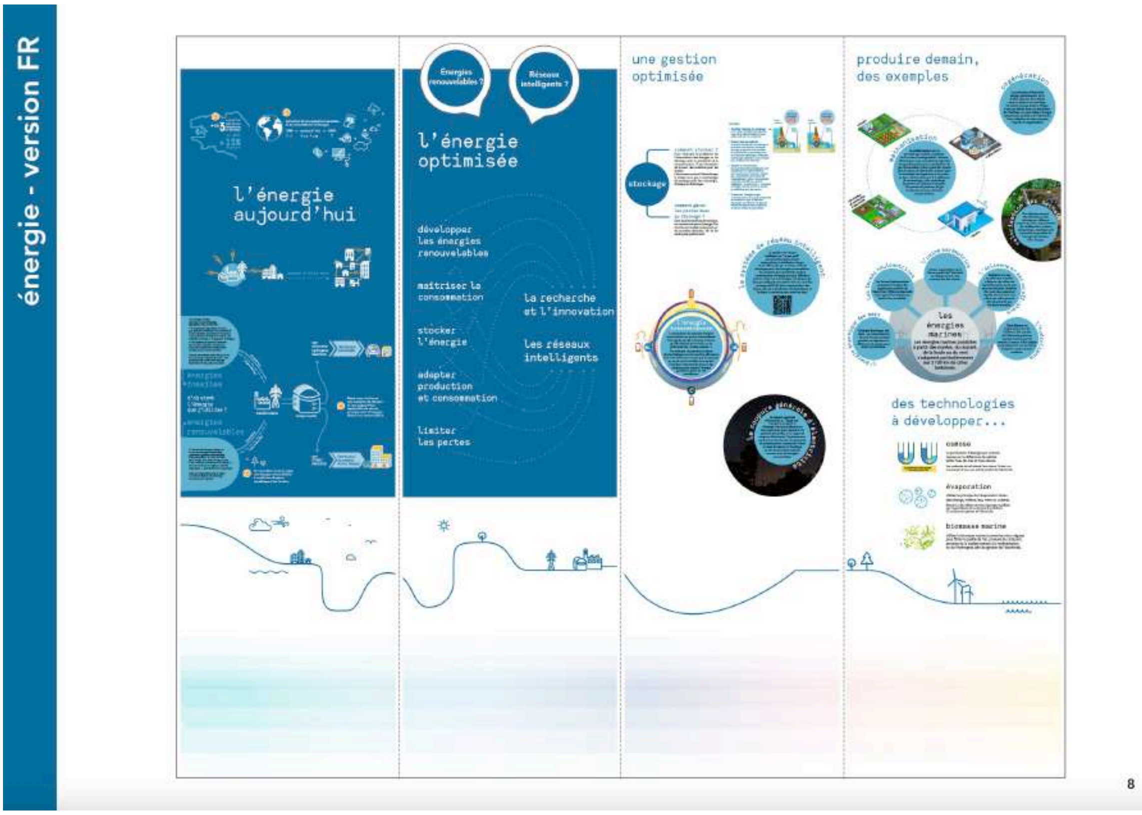
5

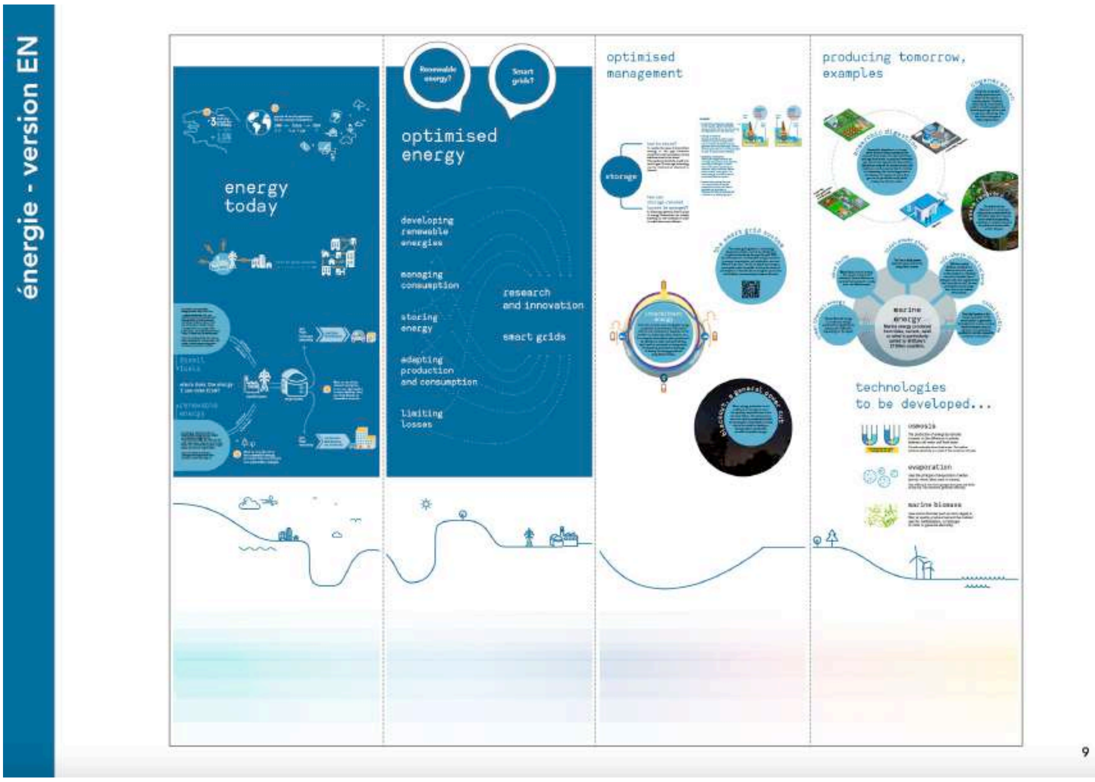
habitat - version FR

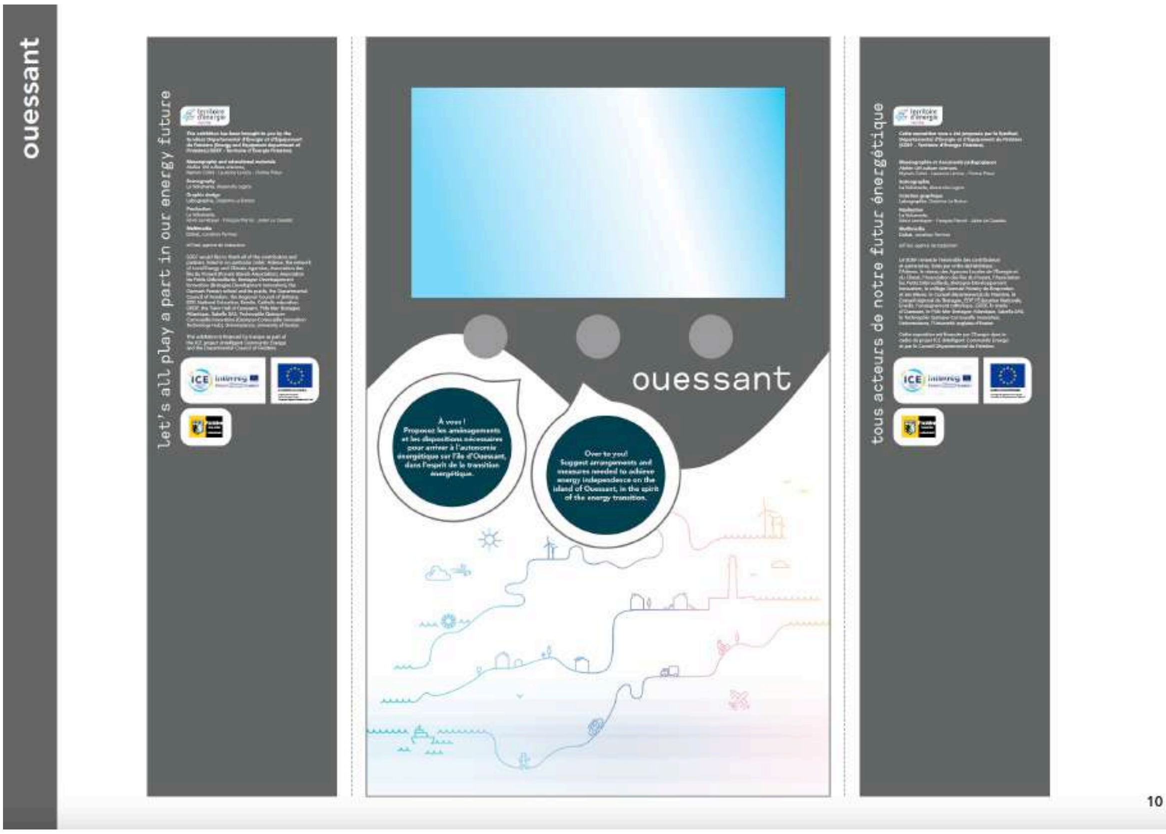
6

habitat - version EN

7


énergie - version FR
l'énergie aujourd'hui
Énergies renouvelables ?
Réseaux intelligents ?
l'énergie optimisée
développer les énergies renouvelables
maîtriser la consommation
stocker l'énergie
adapter production et consommation
limiter les pertes
la recherche et l'innovation
les réseaux intelligents
une gestion optimisée
stockage
produire demain, des exemples
des technologies à développer...
osmose
évaporation
biomasse marine
8


énergie - version EN
energy today
Renewable energy?
Smart grids?
optimised energy
developing renewable energies
managing consumption
storing energy
adapting production and consumption
limiting losses
research and innovation
smart grids
optimised management
storage
producing tomorrow, examples
technologies to be developed...
osmosis
evaporation
marine biomass
9


ouessant
let's all play a part in our energy future
ouessant
À vous !
Proposez les aménagements et les dispositions nécessaires pour arriver à l'autonomie énergétique sur l'île d'Ouessant, dans l'esprit de la transition énergétique.
Over to you!
Suggest arrangements and measures needed to achieve energy independence on the island of Ouessant, in the spirit of the energy transition.
tous acteurs de notre futur énergétique
10