Organic Heat Exchangers

MEETING COOLING DEMAND WITH LOW CARBON SOLUTIONS

O-Hx ORGANIC HEAT EXCHANGERS

ORGANIC HEAT EXCHANGERS IS HOME TO THE PATENTED ENERGIVAULT® TECHNOLOGY, DELIVERING SCALABLE THERMAL ENERGY STORAGE TO REDUCE ENVIRONMENTAL IMPACT AND DRIVE DOWN THE COST OF COOLING.

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White Paper

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BOB LONG

EXECUTIVE CHAIRMAN

BACKGROUND

Organic Heat Exchangers (O-Hx) was founded in 2016 by Bob Long, a mechanical engineer with more than 45 years' experience in refrigeration and thermal energy management. He created O-Hx in response to a growing global need for energy storage, specifically in the cooling sector.

Its patented EnergiVault® technology is capable of storing and delivering significant amounts of thermal energy on demand to reduce the cost of cooling.

Other thermal energy storage systems can be hampered by poor efficiency, limited charging and discharging flexibility and high costs. Rising energy prices and an increasing focus on net zero are key drivers for companies seeking a more sustainable future and reduced operating costs.

Bob and the team at Lancashire-based O-Hx have developed EnergiVault® using physics, engineering and artificial intelligence technology to create the ultimate economic energy management solution.

EnergiVault® is a bolt-on Cold Thermal Energy Storage (CTES) solution, retrofittable for existing industrial and commercial chiller applications and also suitable for new-build projects. The technology adds a range of capabilities to chiller operation, including electrical load shedding and load shifting, providing operational resilience, the potential use of on-site generated renewables and the purchase of energy outside of peak times.

O-Hx TEAM

Bob Long is a Fellow of the Institute of Refrigeration and runs his own specialist refrigeration engineering company, Cool Ideas Ltd. He has an HND in Marine Engineering from Liverpool John Moore and an MSc from Exeter. He is also the founder and Director of Natural Energy Wyre, a tidal energy power generation start-up.

David Grundy has a wealth of financial expertise, as a Chartered Accountant working for over 20 years on corporate M&A, fundraising and IPOs, also with extensive business management credentials. He has advised a range of energy businesses, and is a co-Director with Bob at Natural Energy Wyre.

Geoff Barker is a new business specialist who has spent more than 25 years developing new heating, cooling and local generation businesses, including thermal storage, residential heat pumps, boilers and microCHP and smart heating controls. He is a Fellow of the Institution of Mechanical Engineers and a Chartered Engineer.

Dr David Kane is a Chartered Engineer, with experience in R&D, technology strategy and commercial project delivery within the energy industry, holding a doctorate (PhD) in optimisation and control of energy generation and storage systems. His core expertise relates to low or zero carbon energy technologies for generation a storage, demand side response, virtual power plants (VPP), and microgrids.

We have an experienced and expert team in cooling and refrigeration technology with Bob Long leading the way with 45+ years of experience.

FOREWORD

Cooling is at the very heart of modern life and its benefits, both seen and unseen, affect every part of society. That dependency is destined to grow further, adding to the global challenge of climate change. Because whilst cooling is crucial to everyday life – from keeping food fresh, vaccines useable and people healthy and comfortable – it is also highly energy intensive and environmentally damaging.

According to a joint report from the United Nations Environment Programme (UNEP) and the International Energy Agency (IEA):

"In a warming world, prosperity and civilisation depend more on access to cooling. The growing demand for cooling is creating more warming in a destructive feedback loop.''

There are approximately 4 billion cooling devices in use around the world. The Green Cooling Initiative says that figure is growing by 10 devices every second and estimates it will reach 9.5bn by 2050. This rising demand for air conditioning, refrigeration and data centre cooling would result in a 90% increase in energy consumption and the associated environmental impact without mitigating action.

There is no single solution and it is widely accepted that a varied approach is required, including a reduction in demand through improved building design, better utility regulation and aggressive energy-efficiency strategies.

The Birmingham Energy Institute and the Institute for Global Innovation at the University of Birmingham addressed the issue in the report in **A Cool World:** Defining the Energy Conundrum of Cooling for All. Its key conclusions stressed that access to cooling is essential for meeting the world's social and economic goals, but warned that unmanaged growth represents one of the biggest threats to achieving climate targets for CO_2 emissions. It added that, if cooling is to be sustainable there is a need, not only for more efficient air conditioning and refrigeration, but also a fundamental overhaul of the way cooling is provided with a new needs-driven, system-level approach.

It is here that the technology behind the EnergiVault® can make a key contribution, by making cooling equipment more efficient and helping match high building loads without the need to consume electricity during peak times.

This innovative **Cold Thermal Energy Storage (CTES)** solution is designed to optimise energy usage for chillers in industrial and commercial applications, and provide peak building load cover if required.

Demand for cooling is growing quickly, driven by factors such as climate change, the growth of urban areas, an expansion of the global middle class and higher incomes. A report from The Economist Intelligence Unit (EIU) estimates that annual global sales of air conditioning and refrigeration units will reach 460 million by 2030, compared to 336m in 2018.

Cooling in all its forms offers many crucial and wide-ranging benefits, including how fresh food and medicines are protected, how people stay healthy and comfortable in a warming world, and how critical facilities such as data centres and energy plants are maintained.

Rising temperatures from climate change are increasing the requirement for air conditioning in new markets, as are wealthier households, while the growth of urban areas is significant because cities, by their nature, tend to trap heat.

Environmental incubator and accelerator 350 PPM estimates that cooling technologies (including refrigeration, AC and heat pumps) account for 25-30% of global electricity consumption and 10% of global emissions. In the UK, the Carbon Trust says total refrigeration and cooling demand accounts for 16% of electricity consumption.

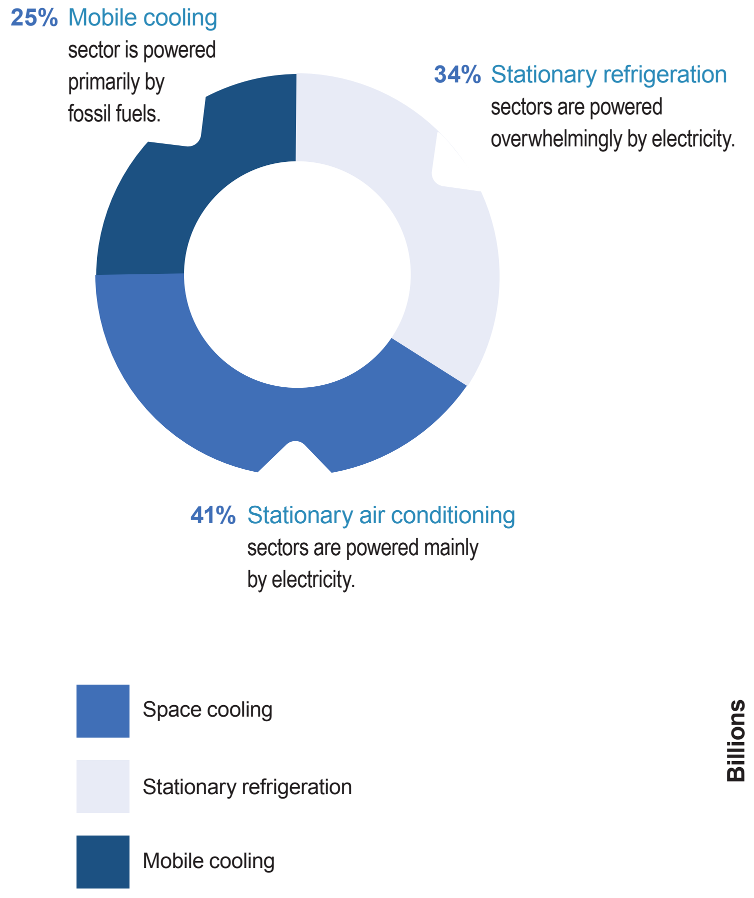
This demand must be met if countries are to meet the United Nations (UN) Environment Programme's Sustainable Development Goals covering issues such as food security, health, inequality, education and employee productivity. But such rapid growth comes at a cost.

Cooling accounts for 20% of global power consumption and 10% of global emissions.

Refrigeration and cooling demand accounts for 16% of the UK's electricity consumption.

* According to the Carbon Trust

Global electricity consumption attributed to cooling
Source: University of Birmingham

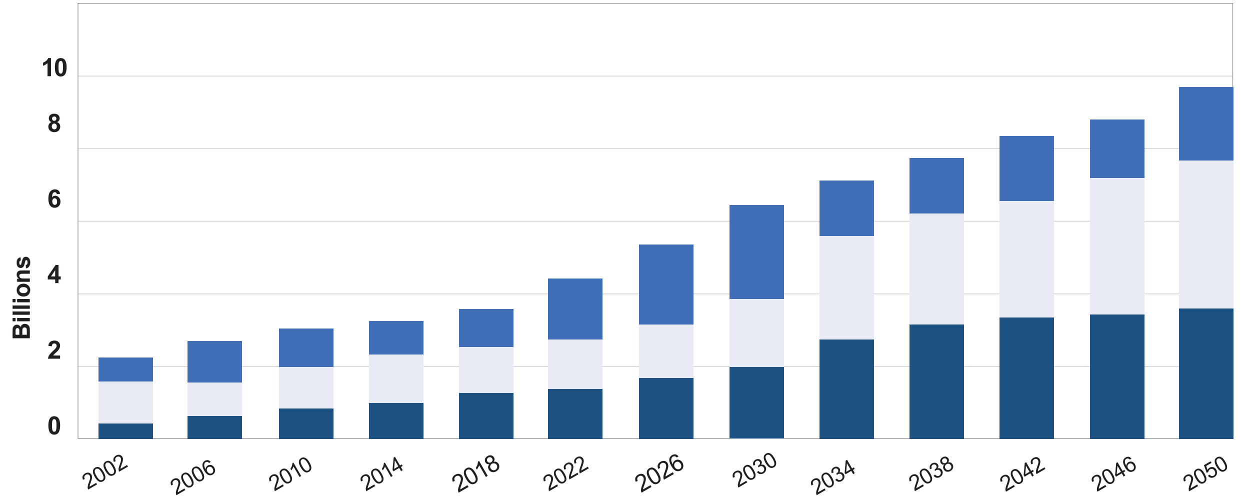


Cooling is a significant contributor to climate change, either directly through emissions from the use and leakage of refrigerants, or indirectly because equipment often operates on fossil fuel-based power. One of the key challenges, therefore, is that cooling is adding to climate change as well as being one of the things we most need to adapt to it.

Almost all cooling systems are powered by electricity, and the growth in cooling will intensify the demand on power grids. According to 2018 figures from the University of Birmingham, **cooling equipment uses 4TWh of energy annually** worldwide, around 3.5% of the total energy demand from all sources, and this is projected to rise by 90% by 2050.

Although grid-supplied electricity is steadily decarbonising in markets such as the UK through a move towards renewable energy, much of the world's electricity is still generated by fossil fuels, resulting in increased CO_2 emissions.

Number of cooling appliances in use globally, (qty of units), with forecast by sector
Source: University of Birmingham



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TECHNOLOGY LANDSCAPE

Mitigating measures

There has long been an acceptance that more must be done to combat climate change. The Montreal Protocol was established in 1987 to regulate the production and consumption of ozone-depleting substances (ODS) used as refrigerants. However, many of the alternative hydrofluorocarbons (HFCs) introduced as a result had high global warming potential (GWP), leading to the Kyoto Protocol and Kigali Amendment to phase down their use.

On a wider scale, The Paris Agreement holds nations legally accountable for their efforts (or lack of) to tackle climate change, while the UN's Sustainable Development Goals are a collection of 17 linked global targets designed to be a "shared blueprint for peace and prosperity for people and the planet''.

A varied and concerted approach is clearly required to address the impact of cooling on the environment across all of these targets, as well as increased measures to reduce the energy consumption of cooling equipment and decarbonise buildings. This includes improved building design and urban planning alongside the adoption of low GWP refrigerants in equipment and district cooling systems.

It also requires new equipment technologies while the improved management of existing devices can help the drive towards Improved efficiency. Incorporating energy storage into a cooling system can potentially reduce indirect emissions. Without storage, cooling equipment has to run to meet demand, even when conditions are not optimal. By separating when energy is imported, or when cooling is generated, from when cooling is used, efficient energy storage enables conventional equipment to be run under non-optimal conditions for less of the time.

Further reading: The Future of Refrigerants with GWP of less than 150.
https://ior.org.uk/public/downloads/iA33H/Franzen_Mills_Lamb_Wiszniewski_Lawton_15_April_2021_TechTak_paper_final.pdf

Different types of technologies can be applied to reduce the cooling industry's impact on the environment.

COOLING NETWORKS

Cooling networks produce and distribute cooling energy through a chilled water network to cool buildings.

COOLING DEMAND REDUCTION

Reducing a building's total cooling load through architectural design, such as shaded areas.

THERMAL ENERGY STORAGE

A system to store energy generated during off-peak hours to be used later during peak demand.

ALTERNATIVE COOLING METHODS

Of which there are many, including air conditioning, and chilled water systems.

ENERGY RECOVERY

Re-use waste energy from one part of the system to part heat or cool elsewhere in the same system or premises.

SUSTAINABLE ELECTRICITY

Includes 4 main options: wind power, solar power, bioenergy and hydroelectric including tidal energy.

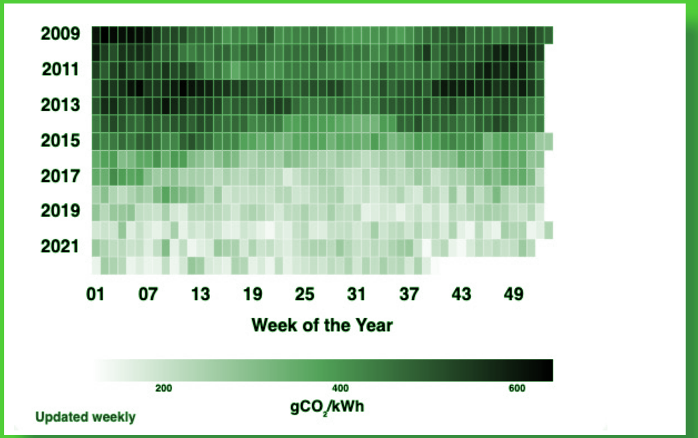
Re-imagine the way we use and deliver cooling. In so doing we need to understand the portfolio of cooling needs, the size and location of multiple thermal, waste and 'wrong-time' energy resources available.

Professor Toby Peters
Professor of the Cold Economy
University of Birmingham

According to the National Grid, the UK has the fastest-decarbonising electricity network of any nation in the world, almost halving carbon intensity from 2009 figures in the summer and an even more significant reduction in winter.

The UK's electricity production is becoming greener, but this is not enough on its own. The dark green squares indicate months where fossil fuels dominated the generation mix, whilst the light grey or white show when the UK has been running on cleaner energy.

History of carbon intensity of generation



https://www.nationalgrideso.com/future-energy/our-progress/carbon-intensity-dashboard

The majority of cooling applications in the UK utilise electricity in some form. With no single solution to reducing the impact of the cooling sector on the environment, the UK's energy providers have been working towards a more sustainable provision of energy for some time, increasing renewable sources such as wind, solar and tidal.

At 7am on Friday 21 April 2017, the UK was operating without coal power for the first time since the 1880s. However, coal power is still used to some extent, underlining that the provision of 'green' energy is at nature's mercy. Wind and solar are not at constant supply levels, so relying on that energy source is not always possible.

Carbon intensity is an important indicator of the environmental impact the energy we use is having in the UK. It provides a measure of how 'clean' our electricity supply is by indicating the grams of carbon dioxide released to produce 1 kilowatt hour of electricity.

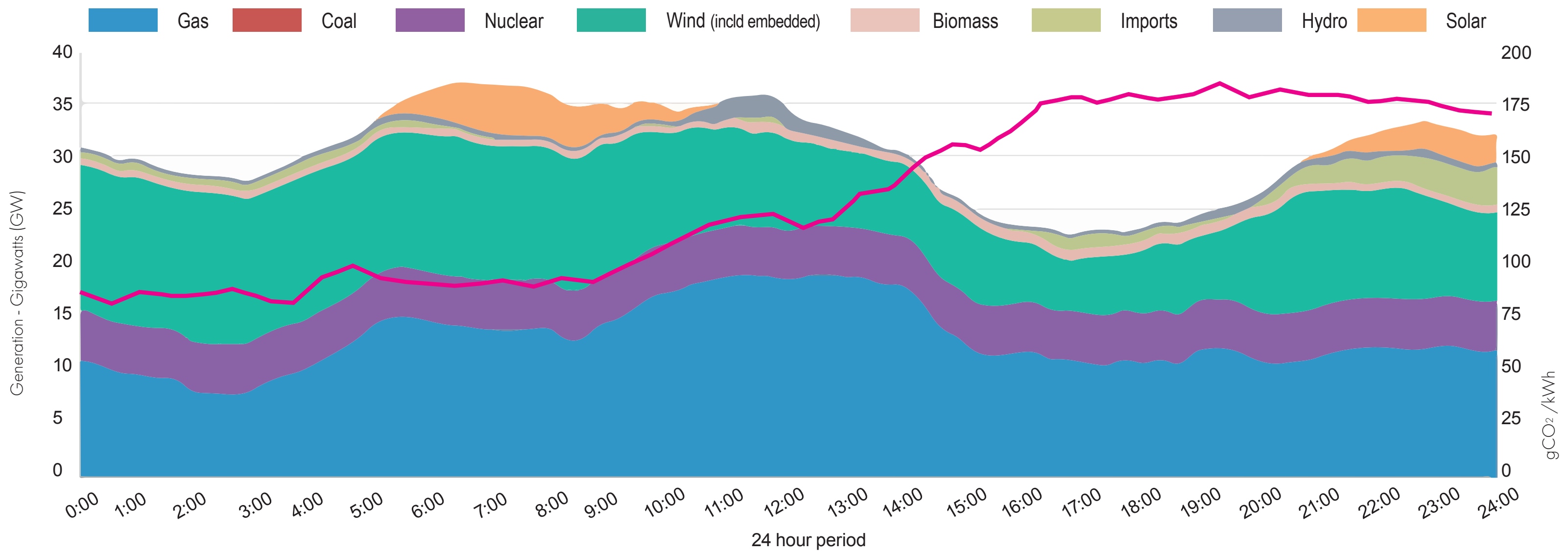
It can be assumed that the more demand on the grid, at a time typified as a peak, the more carbon intensive the electricity supply would be. This, however is not always the case. As mentioned earlier, renewable energy can fluctuate quite a lot in terms of generation, and sources such as wind, hydro and solar will vary not only day-by-day, but also hour-by-hour and month-by-month.

Patterns of electricity use are, by contrast, quite clear to see; UK energy consumption generally peaks between 07:00 and 18:00 each weekday. Renewable sources are prioritised by the simple fact that as supply increases because it is a windy day, for example, then we use more wind-generated electricity to meet demand and lessen fossil fuel use. Generally, the energy source used to balance demand is natural gas.

As more capacity builds in the network for renewable provision, reliance on carbon intensive fossil fuels will decrease. But for the moment, further challenges for improving the physical network need to be overcome to prevent thermal constraints, which are 'energy bottlenecks'. If demand is greater than network capabilities, then bottlenecks occur. In addition, when renewable energy and embedded energy generation is high, bottlenecks can also occur because of the increasing amount of energy the network has to carry. Managing this thermal constraint can cost on average approximately £30 million per month.

The Operability Strategy Report from the National Grid shows that by 2030, some areas of the network will see peak power flows which are 400% greater than the current capability.

Example of the fluctuating energy sources used to produce electricity over 24 hours in the UK with accompanying carbon intensity representation.
Source: data from National Grid ESO



Energy carbon intensity

Renewable energy has very little or no carbon intensity, whereas the use of fossil fuels give a high carbon intensity.

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Cooling load in relation to energy consumption.

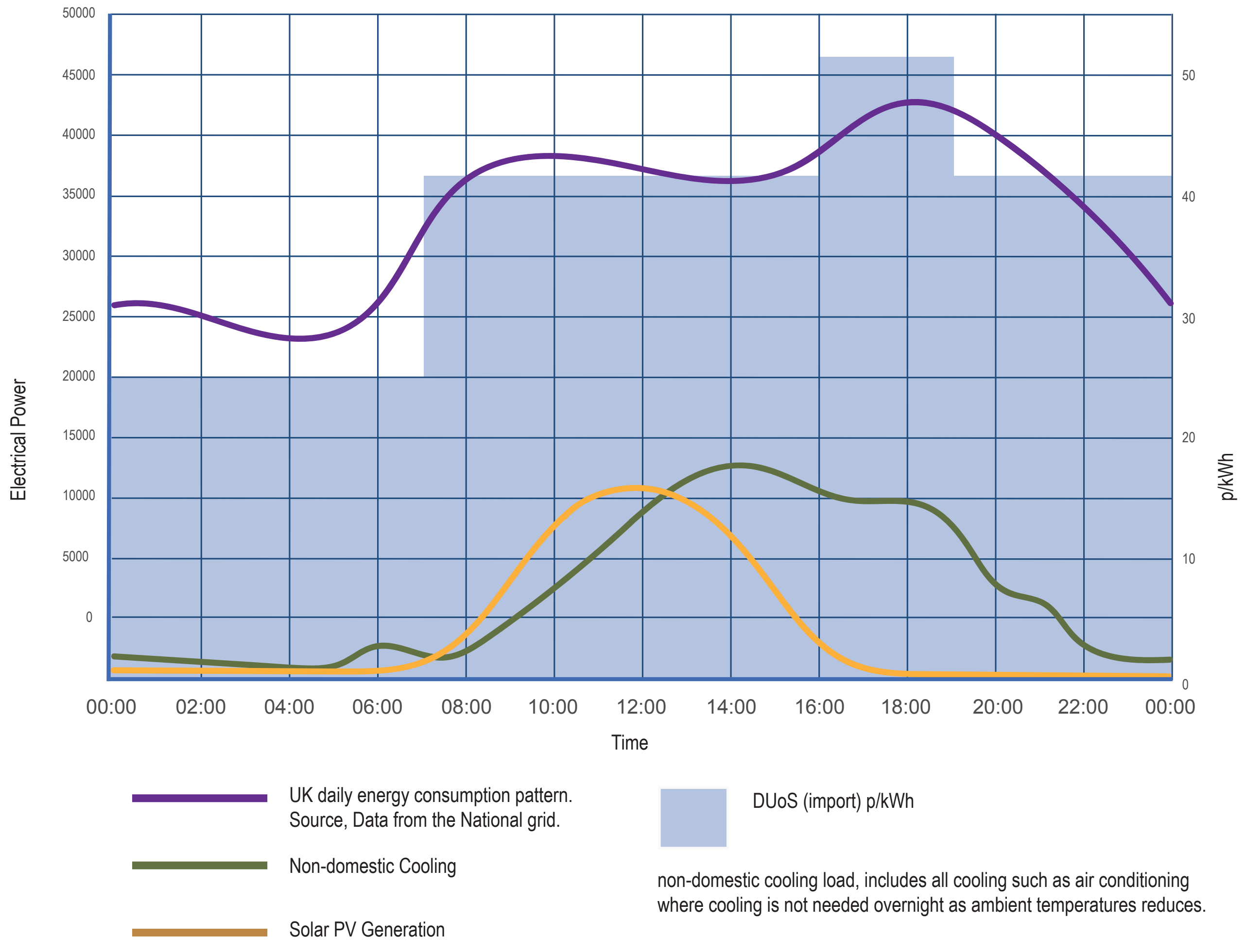
Focus on renewable energy sources and carbon intensity has given rise to 30-minute monitoring of our energy supply, with interactive dashboards and data feeds available from network operators. For the average consumer, this level of information, if harnessed correctly, allows decisions to be made when it is more environmentally friendly and cheaper to operate certain appliances, charge electric vehicles and carry out certain tasks. On a commercial or industrial scale, this pattern of variation is not always possible.

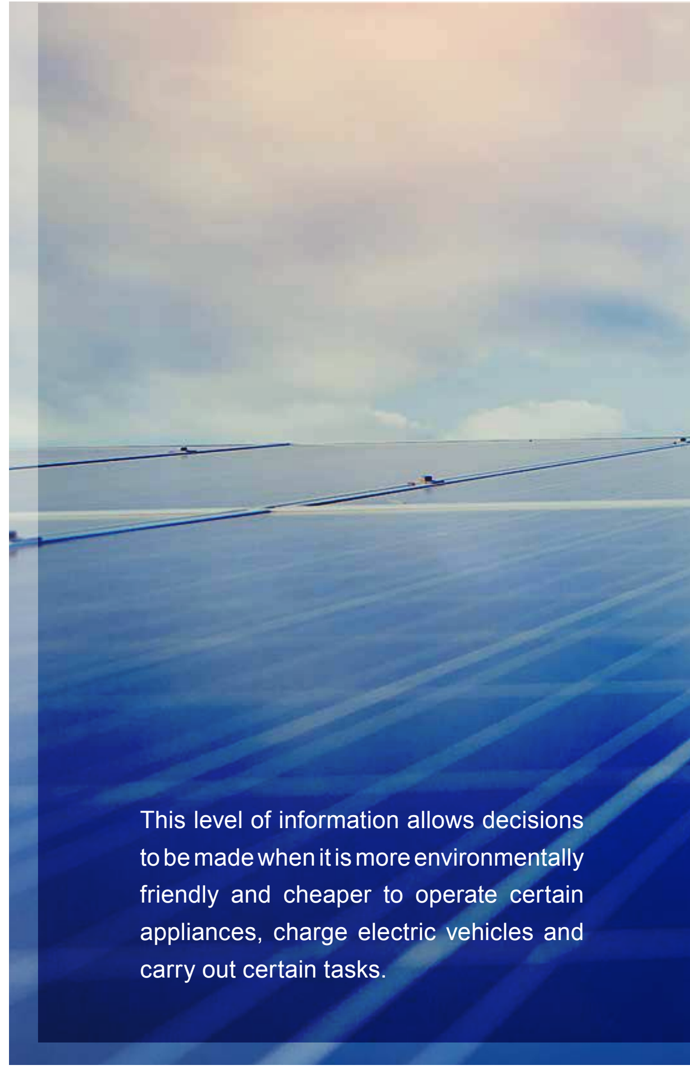
In the cooling sector, demand is usually attributed to higher ambient temperatures, which generally occur in the middle of the day and coincide with peak energy consumption.

The Department for Business Energy and Industrial Strategy (BEIS), 2021 Cooling in the UK report highlights that even with localised renewable energy generation from solar panels, the supply and demand peaks vary at different points in the day. Furthermore, as already outlined, the amount of solar generation or wind generated electricity fluctuates greatly. An ability to automatically and flexibly respond to unpredictable electricity supply conditions, and match this to operational demands, would significantly enhance grid efficiency.

While adding local renewable energy sources to buildings or cooling plant does help to reduce the reliance on the grid and, in turn, fossil fuels, it is not currently a comprehensive enough solution to make any viable impact.

The relationship of energy consumption and production costs across a typical day in the UK
Source: Cooling in the UK, BEIS 2021





Energy storage for cooling is available in a variety of forms.

This can be one of the most effective methods of negating the effects on the environment of high loads during peak energy periods,and can be approached in two different ways.

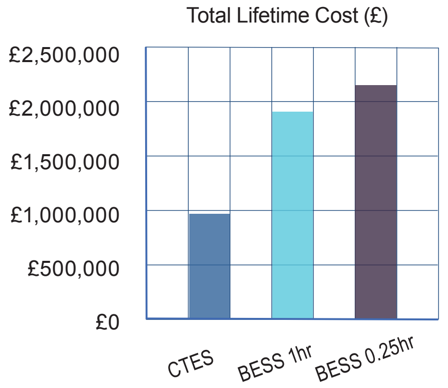
1 Store the electrical energy, captured when network demand is low, to be used when required to power cooling plant.

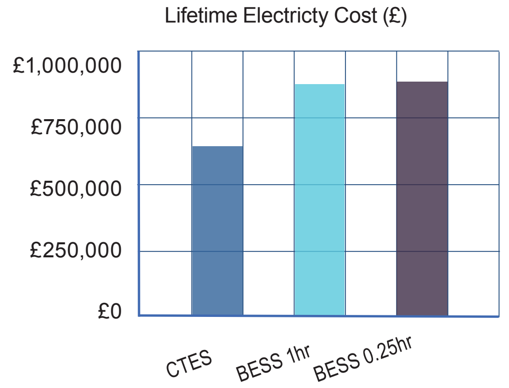
2 Store the thermal energy, generated when network demand is low, to be used when required.

The first solution. Involves the use of **electrochemical batteries**, such as the typical lithium-ion examples in everyday use, which feature a chemical material called an electrolyte. When electrons move from the cathode (+) to the electrode (-), the battery is charged and the chemical potential energy is increased. When discharging, the opposite takes effect.

Lithium batteries degrade over time, losing energy capacity.
It is suggested that when lithium batteries are used as energy storage systems on a large scale, they will need to be replaced roughly every 8-10 years, which can be a costly process, especially when replacing larger industrial variations. These batteries would power cooling plant such as a chiller directly, either taking the place of the supply from the grid or supplementing it.

Comparison based on 2.4MWh of cooling per day, discharged over 1 hour with 20 year life.





CTES (cold thermal energy storage)
BESS (battery energy storage system)

The second solution. Thermal energy batteries, or **Cold Thermal Energy Storage (CTES)** as they are also known, use electricity from the grid to power an integrated chiller or 'charging unit'. This charging unit is typically used to generate block ice which cannot cool heat transfer medium rapidly. In addition an alternative is to use ice slurry which can discharge quicker, due to an increase surface area.

Creating a CTES requires the designer to select a phase change material, this being the substance that will be stored and used to cool down the secondary fluid, or produce. Two main choices exist, utilising **sensible heat** exchange or **latent heat** exchange.

Example of cold thermal storage capabilities

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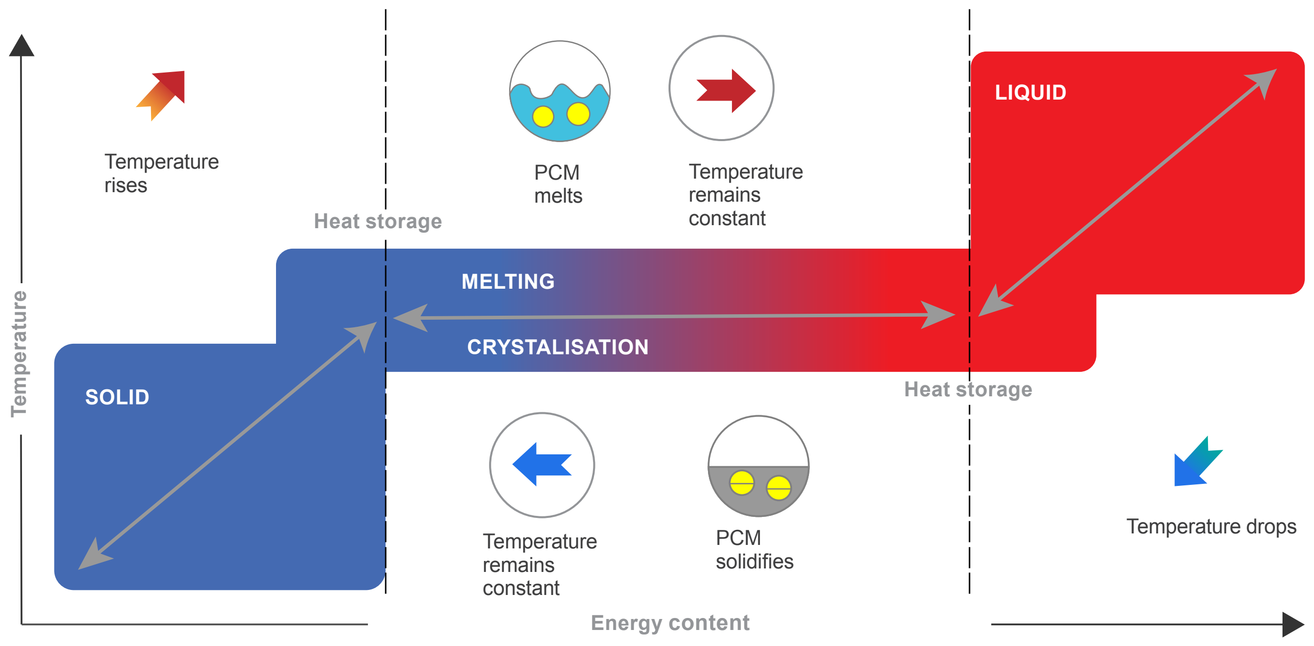
Sensible heat is a term used to describe a change in enthalpy by absorbing or rejecting energy causing a temperature change at a given pressure. For example, one kg of water, which is the weight of one litre of water, will require 4.186 kJ of energy to raise its temperature by 1°C at atmospheric pressure. Similarly, it will be required to reject 4.186 kJ of energy to decrease by 1°C. The phase of the water does not change, it would remain as a liquid between 0 and 100°C

Latent heat, or latent heat of fusion, describes the change in enthalpy of a substance by absorbing or rejecting energy, causing a phase change at a given pressure. Once water reaches 0°C it needs to reject 333.5 kJ/kg to turn from a liquid to a solid, or in this case, ice. No temperature change occurs, but energy transfer is still present.

Basic principle of thermal energy storage with latent heat exchange.
Source: Thermtest



From a design aspect, if a sensible energy store was to be used, then a large amount of liquid would be needed to harness enough energy to meet the demand. Furthermore, the changes of volume and therefore pressure with temperature change also need to be factored into design. If a phase change energy store was to be used, then almost 80 times the amount of energy could be absorbed or rejected by ice than it could the same weight of liquid.

Rate of energy transfer

Ice has been used as a CTES for centuries, dating back to the early Egyptians who used rapid evaporative cooling to generate their ice. Its applications now vary greatly, but one challenge remains unchanged – how do we cool items quickly?

In the agricultural and food sectors, blast chilling can take place, reducing produce temperature rapidly. However, on fishing vessels such mechanical plant is not normally available and ice is used to chill produce quickly, preserving its quality and stopping it from spoiling during long trips.

It has already been established that ice can absorb a lot of energy, relatively speaking, but the available surface area of the ice plays a large part in how quickly that energy can be absorbed and the rate of temperature reduction, therefore, of the fish. Therefore, you regularly see fish covered or layered in ice shards, but rarely see one laid on a block of ice.

The same principles of CTES can also be applied to cooling liquids – fluids that can be used for process cooling or for comfort cooling. A building's chiller would normally circulate chilled water or 'heat transfer fluid' around a building serving evaporators of varying purposes. If the heat transfer fluid came into contact with ice, then its temperature would potentially reduce and either increase its energy absorption capabilities or reduce the amount of work the building's chiller would have to do to reduce its temperature again. The greater surface area of ice that the heat transfer fluid comes into contact with, the more energy is transferred and the greater the cooling effect.

It is here that the design of the CTES is crucial.
How can ice crystallisation be maintained, without forming a solid block and therefore reducing the contact surface area?

ENERGIVAULT® OVERVIEW

To provide an insight into the capabilities and operation of a CTES, the EnergiVault® is a leading example of how energy can be harnessed when at its cheapest and most environmentally friendly, and assist existing chilled water systems in becoming more cost-effective, raising overall efficiencies.

The EnergiVault® consists of a charger and thermal battery; it generally integrates with an existing chiller but can provide cooling on its own.

The system's charger is designed and calibrated to provide evaporating temperatures set according to the fluid (heat transfer fluid) circulating in the buildings existing cooling system. Its tolerance is set to reduce the temperature and, therefore, the energy of the heat transfer fluid until ice crystals begin to form, creating a working fluid of ice slurry.

The ratio of solid phase matter to liquid phase matter is critical in this ice slurry as this mix is the difference between an ice slurry and a structure that is no longer fluid. As previously discussed, the EnergiVault® must maintain a working fluid to maintain a high heat exchange area. Therefore, the ice crystals are kept between 0.1 and 1mm to maintain fluidity and take the shape of a perfectly spherical crystal to avoid the clumping typically found in dendritic crystals.

The ice slurry is stored within a large thermal vessel, and an interface heat exchanger is used to discharge the cooling into the working fluid.

A simple blending valve allows the integration of the EnergiVault® into any existing chiller. The blending valve either supports the current chiller operation by adding a controllable amount of additional cooling or is positioned to provide 100% cooling capabilities.

EnergiVault®
thermal battery

Cooling capacity

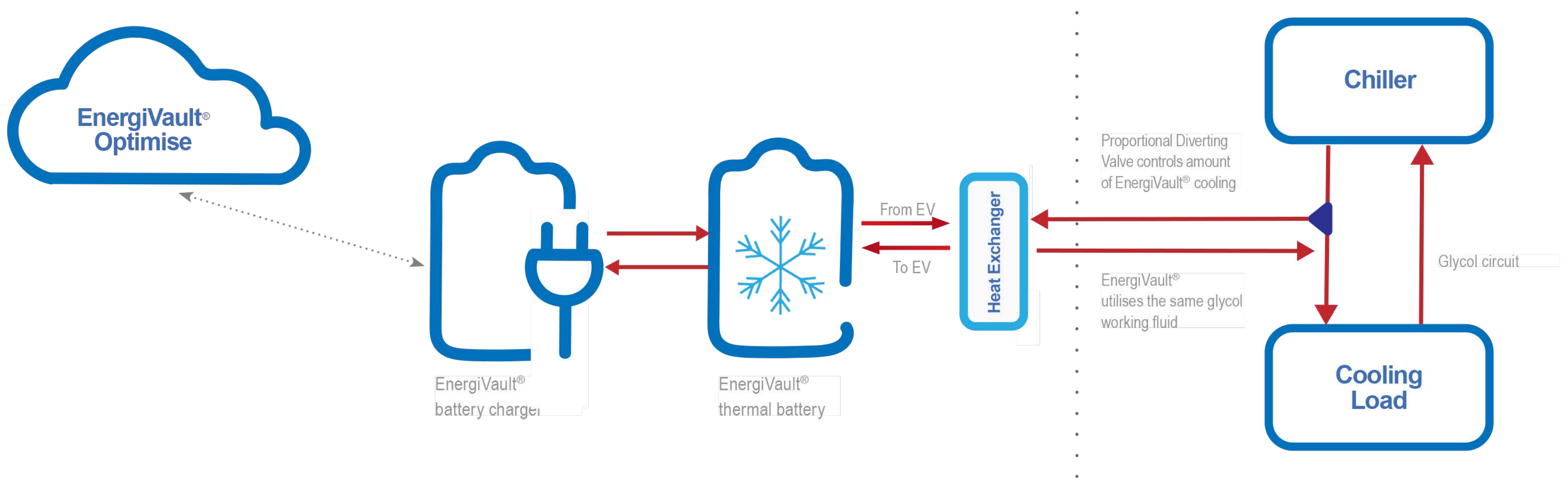
The overall control strategies of EnergiVault® can become quite extensive, as described later, but here we focus on its primary purpose, **how does the EnergiVault® know its thermal store is 'charged'**? As ice crystals form, the amount of ice slurry within the cylinders increases, meaning less working fluid. The working fluid is of greater density than the ice crystals, and therefore the weight of the cylinder decreases. In contrast, as the amount of ice slurry decreases, the weight of the cylinder increases because of the increase in heat transfer fluid.

This weight change is monitored by load cells and configured to calculate the amount of cooling capacity in the thermal store and, in turn, the state of the ice slurry, leading to its agitation to maintain a working fluid rather than solidification.

Note: Working fluid or heat transfer fluid is the medium that is cooled when in contact with the ice.

ENERGIVAULT® SUPPORT COOLING

EXISTING/CONVENTIONAL REFRIGERATION SYSTEM



TIME OF USE SHIFTING

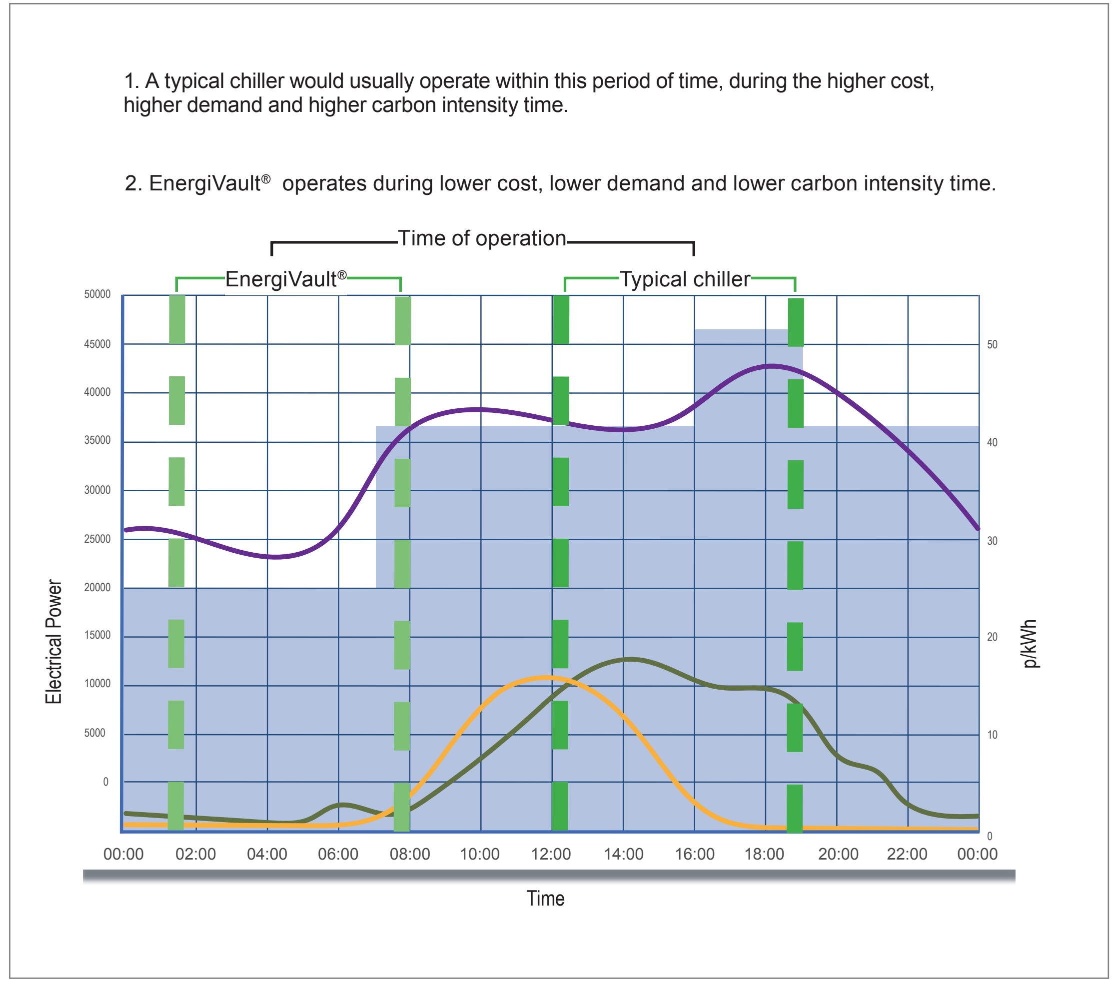
CTES systems like EnergiVault® provide significant benefits when considering Time of Use, for the energy consumed to provide cooling – and as a complete backup cooling system.

A simple rule of thumb would be to utilise electricity during the night on a cheaper energy tariff to reduce the cost of operation. However, there are a lot of other factors that make EnergiVault® even more beneficial to the bill payer and the environment.

Scalable control strategies allow integration into existing systems and live external data. Numerous data points need to be monitored and assessed to map a complete system's efficiency, operating costs and impact on the environment.

These include, but are not limited to:-

- Time of Use shifting
- Chiller optimisation
- High heat grade heat recovery
- Low heat grade heat recovery
- Solar PV (local energy generation)
- Energy monitoring insight



CHILLER OPTIMISATION

Existing chiller efficiencies and performance

By the nature of their design, chillers fluctuate their capacity and required input power depending on high ambient temperature or high heat rejection water circuit temperature. In addition, the load percentage in relation to the chiller capacity also holds a significant impact.

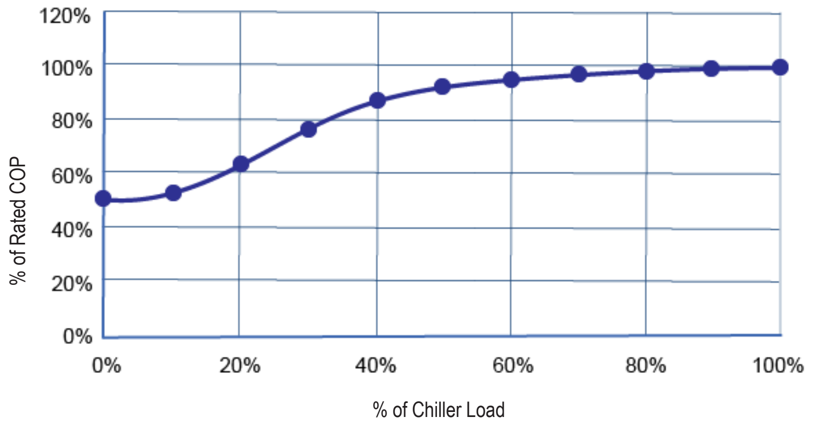
As ambient temperatures increase for air-to-water systems, or water rejection circuit temperature increases for water-to-water systems, maintaining energy exchange becomes increasingly difficult with higher operating pressures of the refrigeration circuit required and, therefore, a higher electricity consumption. Furthermore, as the load fluctuates away from the system design conditions, the chiller's efficiency reduces as the load gets less.

Inverter control and the staging of chiller modules can reduce the amount of system efficiency decrease, but it is still an unavoidable consequence.

Energy cost and carbon intensity

Introduced earlier, the cost of energy production and the carbon intensity of our electricity supply fluctuate daily or even hour by hour. The cost of electricity supply per kWh becomes less as the national grid does not have to import as much electricity when demand falls. What is more, the carbon intensity of the supply fluctuates and becomes more environmentally friendly as the grid can use more renewable energy.

Existing Chiller Part Load Performance

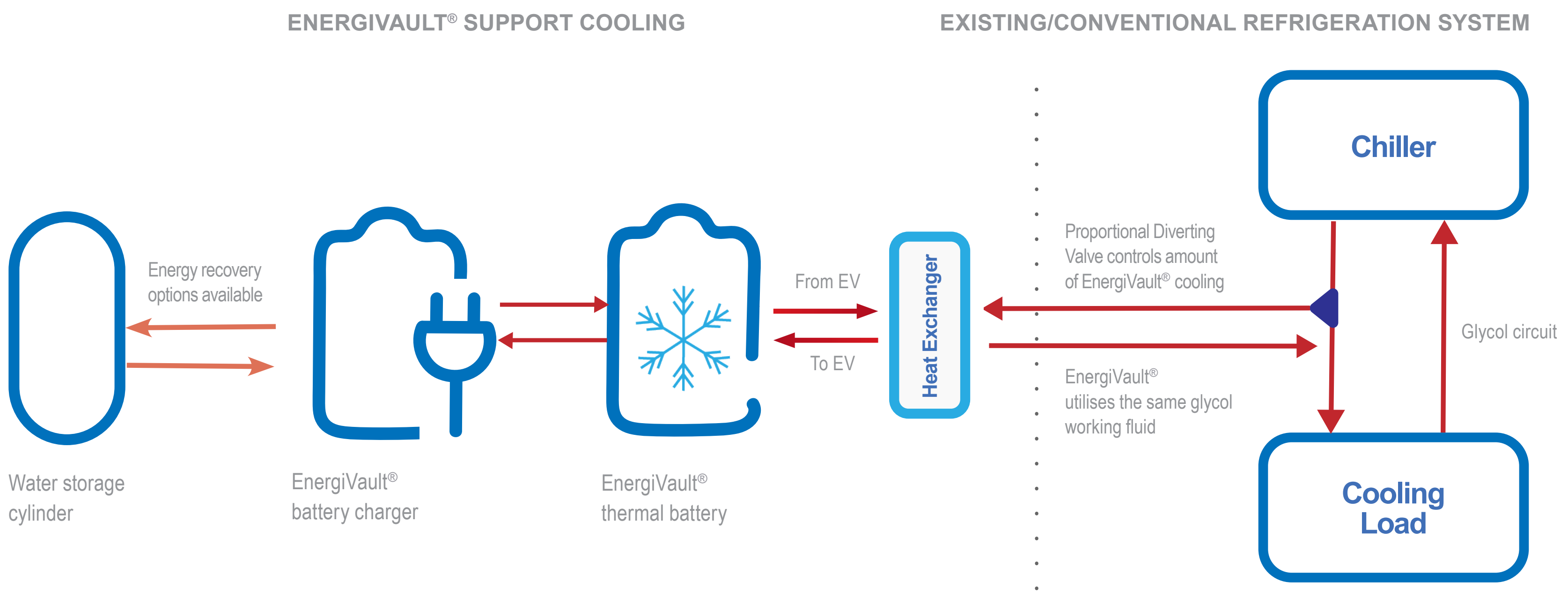


LOW GRADE AND HIGH GRADE ENERGY RECOVERY OPTIONS

With every cooling process, the by-product is 'waste heat', and the cooling process of the EnergiVault® is no different. As heat energy is removed from the parent fluid circulating around a building to form ice slurry, the waste heat is rejected into ambient air, typically at the condenser. Whilst remaining reusable energy, it is lost from the system.

To maximise system efficiencies and add further weight to the cost and environmental savings, this **waste heat can be utilised to generate hot water, space heating and other process heat requirements.**

Both high (100°C) and low (40°C) grade heat generation is possible with multiple storage options to harness the heat recovery potential, decoupling from the EnergiVault® charging process, for flexible, on-demand, use.



SOLAR PV INTEGRATION

Premises, such as food production factories, with large renewable energy generation systems can benefit end users through operation cost reductions. Usually, the Distribution Network Operator (DNO) will limit the amount of electricity that can be exported to the grid to avoid a surplus supply when demand is low. Still, with EnergiVault®, this complication can be removed.

By integrating on-site generation, such as solar PV and wind turbines, EnergiVault® can adjust its charging period to maximise the consumption of energy that is being generated on-site. In addition, it displaces high-cost grid-imported electricity at peak times.

ENERGY MONITORING INSIGHT

How to maximise all the possible energy saving benefits:

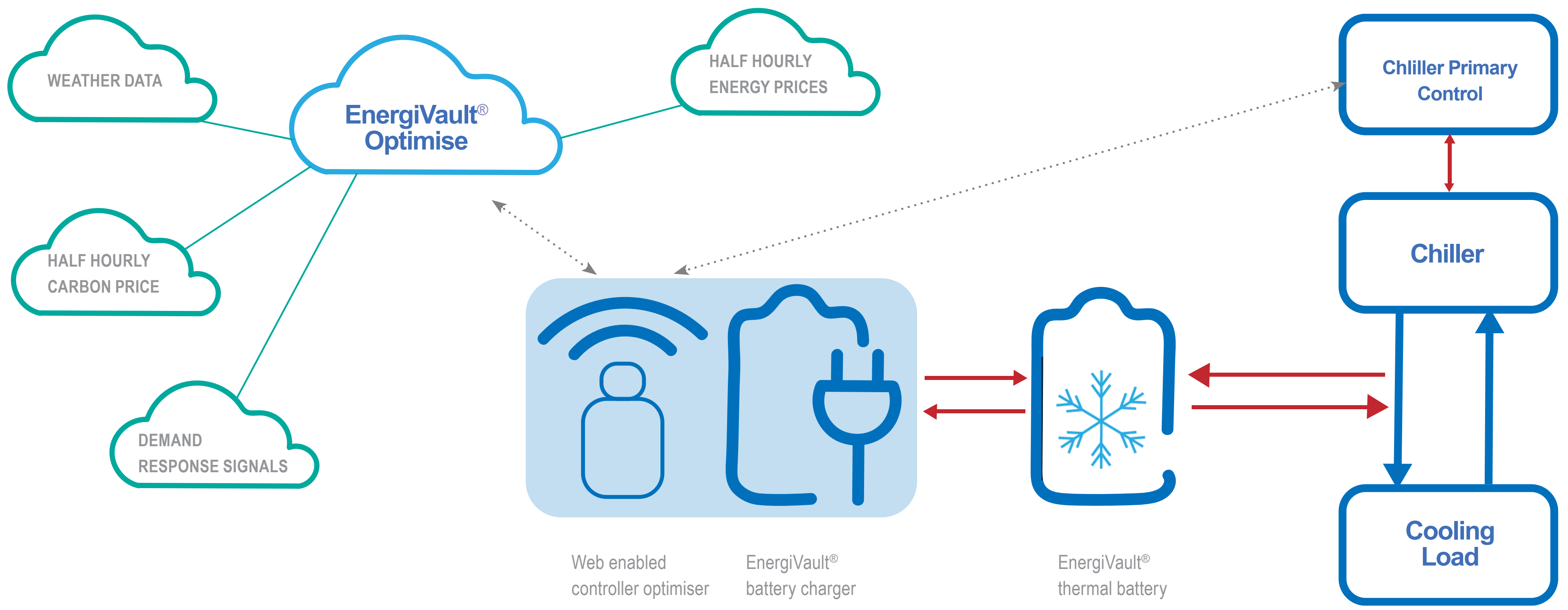
- Produce a system that can integrate with existing installations and monitor its performance and that of the existing system(s).
- A solution that can adjust third-party setpoints depending on load requirements and judge efficiencies with enough intelligence to maximise them by completing the takeover of demand or providing supplementary cooling.

Monitoring half-hour energy supply data allows the judgement of:
- When to charge the EnergiVault®,
- When to turn existing chillers off, and
- When to operate in unison.

Additional benefits are found by coordinating with renewable energy generated onsite, through solar, wind or combined heat and power – utilising 'free energy' rather than exporting into the grid.

There is no single solution to solving the energy crisis we are currently experiencing. However, EnergiVault® provides a comprehensive method for negating the effects on operating costs whilst reducing environmental impact.

An optimisation engine can realise EnergiVault's full potential.



ORGANIC HEAT EXCHANGERS

ECONOMIC AND ENVIRONMENTAL PROPOSALS

EnergiVault® is designed to be scalable according to site and financial requirements and therefore both environmental and operational cost benefits are variable. We estimate that by operating EnergiVault® alongside an existing chiller installation, savings of up to 69% can be realised against site cooling costs with up to 64% reduction of CO_2 emissions.

Plug and play style integration provides an ideal model to create a system that will offer chiller optimisation, and forecasting through energy monitoring insight, Time of Use shifting, water production through heat recovery and power generation with solar PV.

Cost-saving breakdown

A site modelled to have 1,825 MWh of cooling demand per annum and a heating requirement of 912.5 MWh provided by gas boilers has an operational cost of £667,494. This includes any other electric demand not attributed to cooling or heating.

Savings:

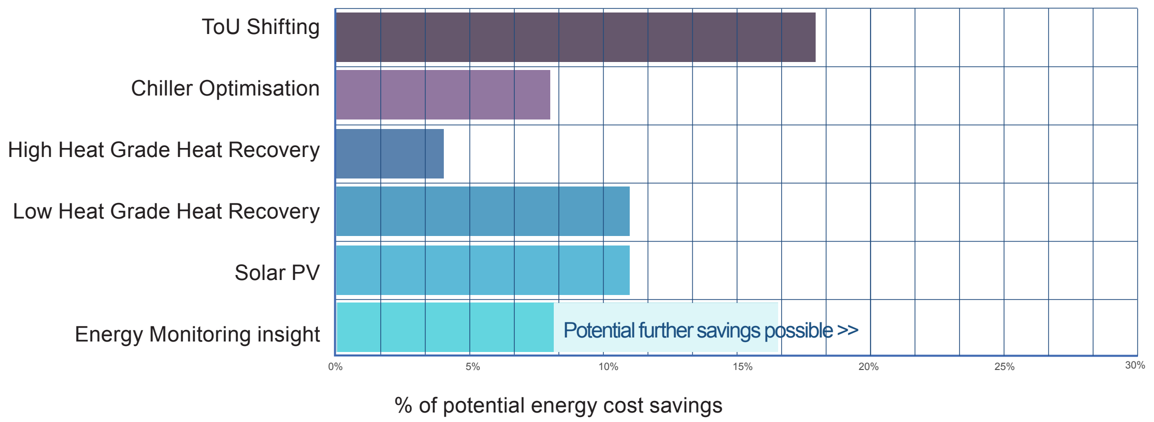
Time of Use shifting	(£51,392)
Chiller optimisation	(£9,636)
High grade heat recovery	(£10,038)
Low grade heat recovery	(£27,603)
Solar PV	(£26,499)
Energy monitoring insight	(£20,025)

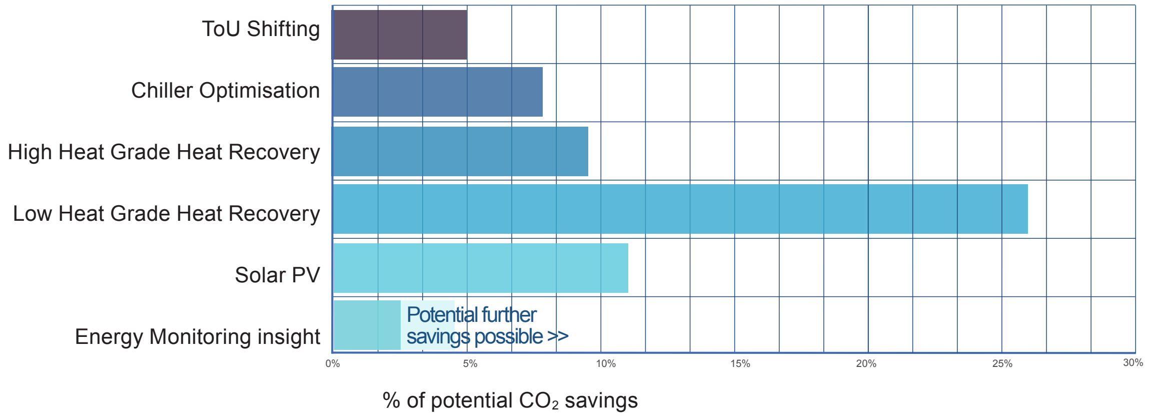
With an estimated purchase price of £250,000 a payback time of 1.8* years can be realised.

*Adding EnergiVault® onto existing chilled water system.

A total gross saving of £145,192 can be achieved with a net saving of up to £139,000 once EnergiVault® operation and maintenance costs have been removed. With an estimated purchase price of £250,000, a payback time of 1.8 years can be realised.

Energy costs and CO_2 reduction forecasts against a building's existing energy usage





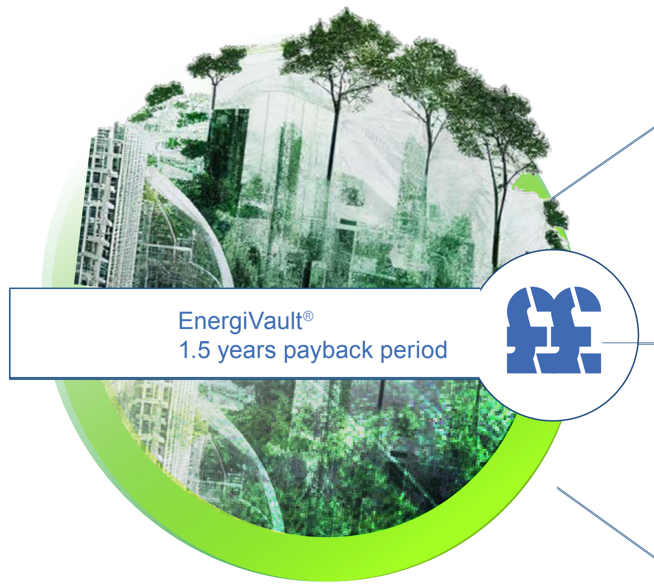
Using EnergiVault® instead of procuring additional chillers can offer **payback on investment within 1.5 years** once purchase, operation and maintenance costs have been taken into account.

ENERGIVAULT® VS ADDITIONAL CHILLER

Increased peak cooling loads generally mean adding more chiller modules to a cooling system, but is increasing chiller capacity the right solution? With EnergiVault®, reduced risks of production shutdowns, spoiled products, or compliance issues can be negated due to the benefit from additional chiller capability. However; the additional added benefits of ToU shifting, chiller optimisation, heat recovery, and energy monitoring insight optimisation can be applied to the site's entire cooling plant, gaining significant financial and environmental benefits.

In addition, the trickle charge nature of operation of EnergiVault® reduces the requirement for facility upgrades or potential additional operating costs from the grid network.

Considerations for an additional chiller*



Initial investment cost
Cost of chiller, electrical network upgrade, facility upgrades.

Risk of production shutdowns during installation
Reduce risk of production shutdowns, spoiled product, or compliance issues.

Additional operational costs
Operational and ongoing energy costs, maintenance and repairs.

*EnergiVault® vs additional chiller in response to increased cooling load

Full-scale testing of the EnergiVault® cold thermal energy storage system from Organic Heat Exchangers (O-Hx) has seen performance exceed expectations in areas including peak load support, resilience and reliability.

A commercial demonstration unit installed at the Alnwick facility of drug development and manufacturing accelerator Quotient Sciences earlier this year, with benefits to date including:

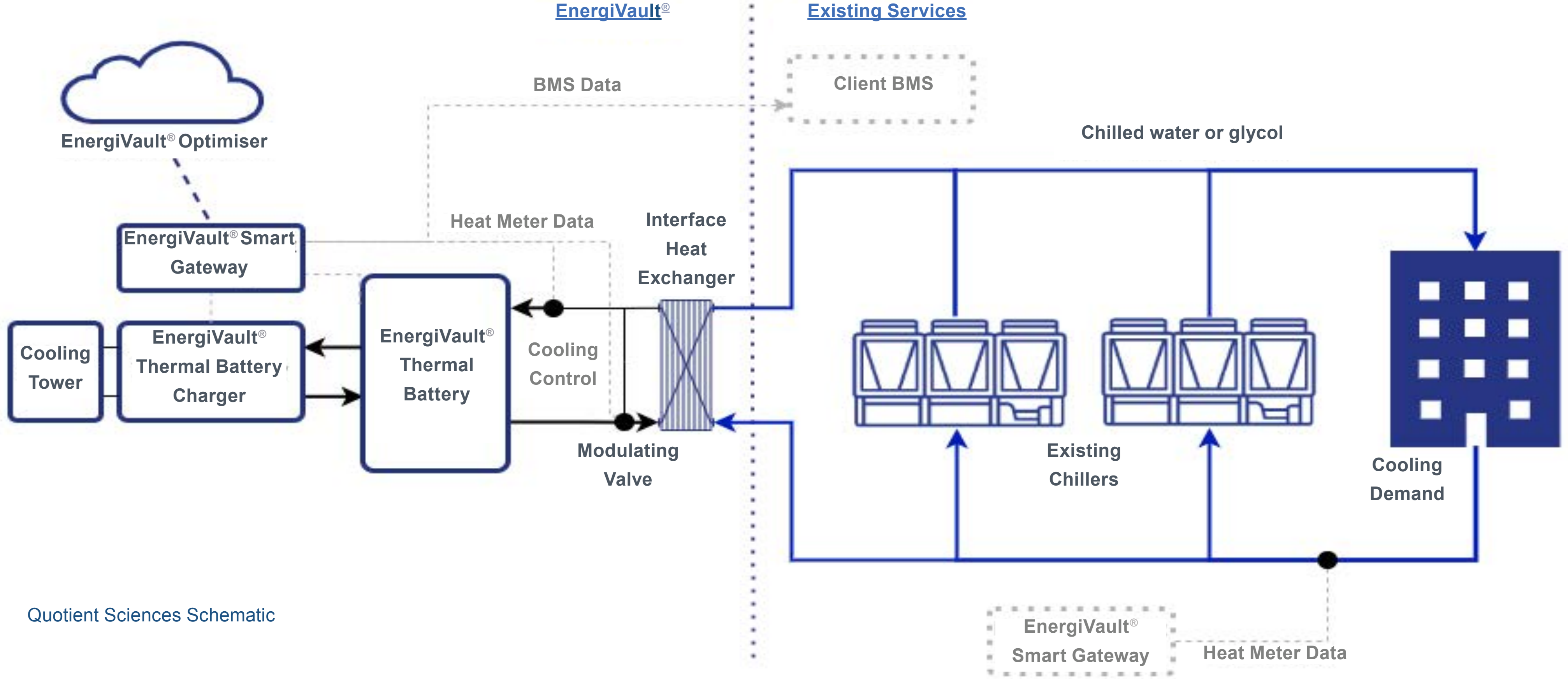
- **Economic savings** from charging with cheaper overnight electricity and from efficient trickle charge of the battery to replace inefficient chiller cycling.
- **Continuity of operations** under high temperatures / humidity, when previously cooling demand could not be supported by existing systems.
- **Resilience** from always having cold energy stored on site, in case of core system failure or shut-down.

Bob Long, O-Hx, Executive Chairman and founder, said: "EnergiVault® has revelled in the high summer temperatures, displaying the ability to deliver huge amounts of thermal energy in support of struggling cooling equipment. We continue full-scale testing at Quotient Sciences, where our performance expectations were surpassed on many levels, including peak load support, resilience and reliability. With high confidence from this unit, commercialisation plans are now in place to be able to meet anticipated demand."

Stuart Munro, Head of Facilities at Quotient Sciences (Alnwick), added: "O-Hx have been extremely professional, taking their proof-of-concept to a working unit that is now helping to support our site cooling demands. They managed to do all this without causing any disruption to our business.

"Quotient Sciences is committed to reducing its carbon footprint and energy consumption at every opportunity. It is innovations such as the EnergiVault® and engineers committed to change that our planet needs now."

The Alnwick site has two 240kW chillers, providing a cold water circuit to support temperatures of 5-15°C, with an annual electricity consumption for refrigeration of ~250MWh. The site experiences pinch points arising from chiller cycling and an inability to support building demand in high weather temperatures, resulting in operating risk to production from loss of cooling capacity.



Quotient Sciences Schematic

The demonstration unit was installed in early summer 2023. Part-funded by a RedCAT grant from East Lancashire Chamber of Commerce, the purpose was to:

- Accumulate test data to demonstrate the operating characteristics of the EnergiVault® system, particularly its discharge flexibility and performance.
- Provide a working unit for demonstration to potential customers.
- Allow real-life testing of product design and componentry to facilitate productionisation.

Installation

The system at Quotient Sciences comprises:

- EnergiVault® Charger (EVC) – up to 50kWt refrigeration circuit, capable of producing 10 tonnes of binary ice per day
- EnergiVault® Store (EVS) – 650kWht rated battery
- EnergiVault® Gateway (EVG) – providing cloud dashboard and integration to the building management system (BMS)

Installation, commissioning and component testing was carried out in April-June 2023, with optimisation and operational testing carried out in June/July. Since then, the system has been running under a series of test regimes and operating modes, with data collection and testing continuing.

Performance results

Quotient Sciences required EnergiVault® to support its systems in three of the four standard operating modes:

1. Chiller optimisation – discharging to avoid inefficient chiller cycling.
2. Peak demand support – discharging when existing systems are unable to cope with cooling demand, or to replace existing chillers (eg for regular maintenance).
3. Uninterruptible cooling – retaining a proportion of available stored energy at all times, to cover any unforeseen chiller outages.

The fourth operating mode – load-shifting – has been tested via full charge-discharge routines but not directly tested on an operational basis due to Quotient's operating requirements and tariff structures.

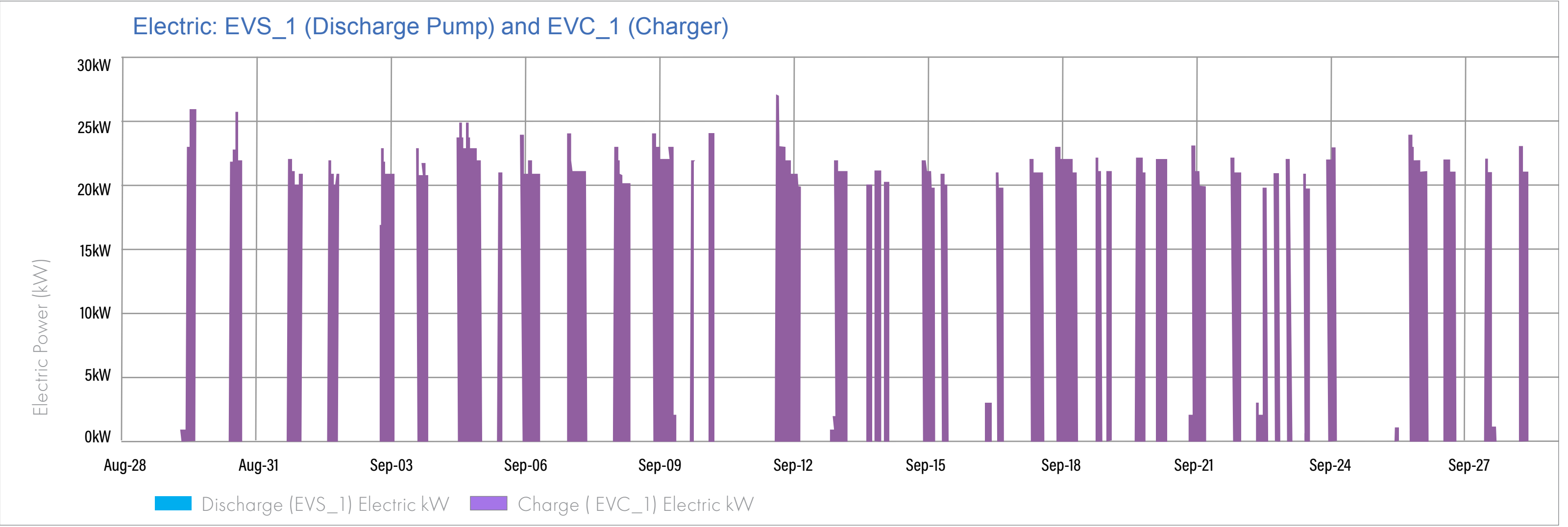
In setting out performance results, two sets of data are presented:

1. Live data, extracted from the Customer Dashboard for the 4-week period from 28 August- 24 September 2023. This records minute by-minute performance, visually allowing day-by-day performance to be observed.
2. Average data for the complete test performance to date, calculated from data extracted from the Customer Dashboard.

EnergiVault® Charger (EVC) performance

The EVC has been tested at various charging rates, notwithstanding that the standard operating procedure is eco-charging at constant speed.

To illustrate daily performance, the graph below shows electrical input to the charger for the 4-week period, showing speed and duration of charge:



Graph 1

Charge rates have been consistent across the period, averaging input electricity of ~20kW.

This low-input charge capability gives EnergiVault® a significant advantage over on-demand chillers, which typically require much higher electrical inputs to deliver similar performance.

Differences in charge duration reflect the demands placed on the battery – EnergiVault® can either partially charge, or fully charge from a partially-discharged battery, as required. Longer charge periods in the earlier part of the graph relate to a period of warmer weather, when the system was providing greater cooling support to the facility, and therefore a longer charge period. The shorter periods of charge in the later part of the month illustrate the flexibility in part-charging.

EnergiVault® battery (EVS) performance

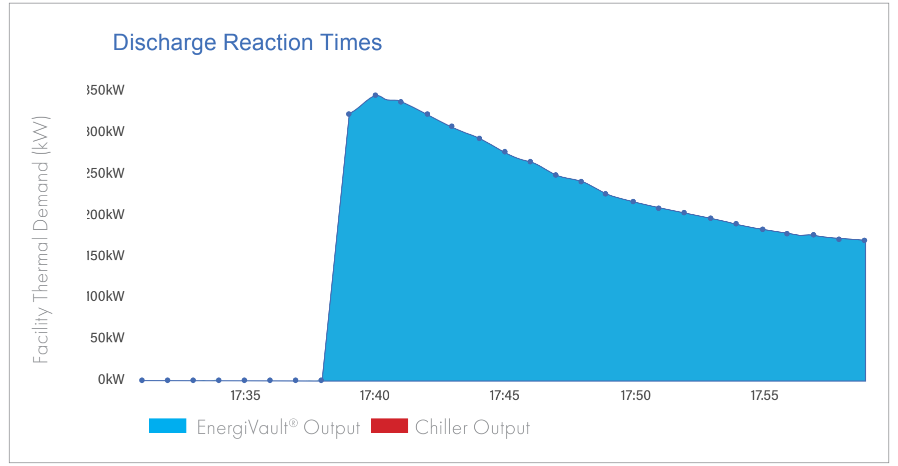
As noted previously, EnergiVault® has four standard modes which are completely integrated and can operate simultaneously. The demonstration unit has been operating under instruction from the Quotient BMS, rather than utilising proprietary optimising software. As such, EnergiVault® has effectively been operating as a third chiller, providing support to the existing two chillers as required.

Reaction times

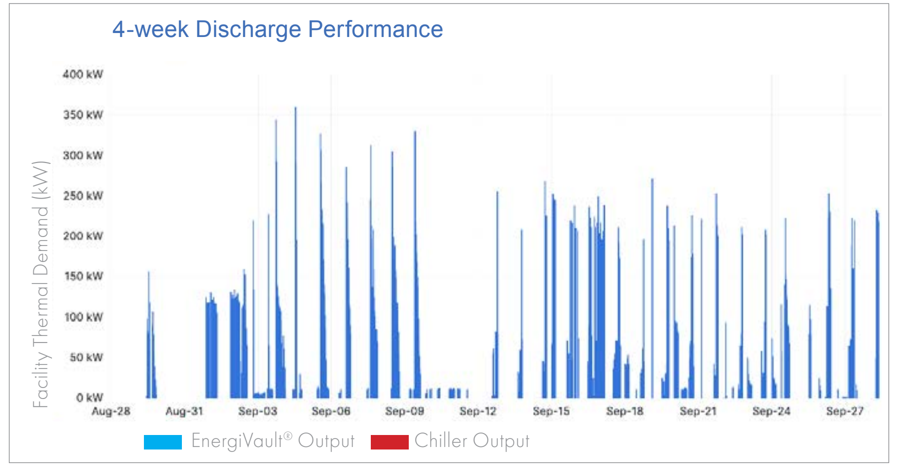
From being asked to provide cooling support, EnergiVault® has been instantaneous in discharging, without need for a ramp-up period. As shown in Graph 2, an illustrative 30-minute window from the Customer Dashboard, with peak discharge rate achieved after minute 2 of instruction to discharge. The following slow-down in discharge rate arises as cooling demand declines with the return temperatures being regulated down to a constant level from an over-heated state.

4-week discharge performance

Graph 3 mirrors the charger performance above, showing rate of battery discharge over the 4-week period: Unlike charging profiles, there is much more variability on discharge performance, with EnergiVault® providing cooling support flexibly on demand and at far higher energy levels. The higher peaks in the earlier period correspond to higher ambient temperatures – core cooling systems are insufficiently sized to support facility demand, with EnergiVault® providing peak demand support.



Graph 2



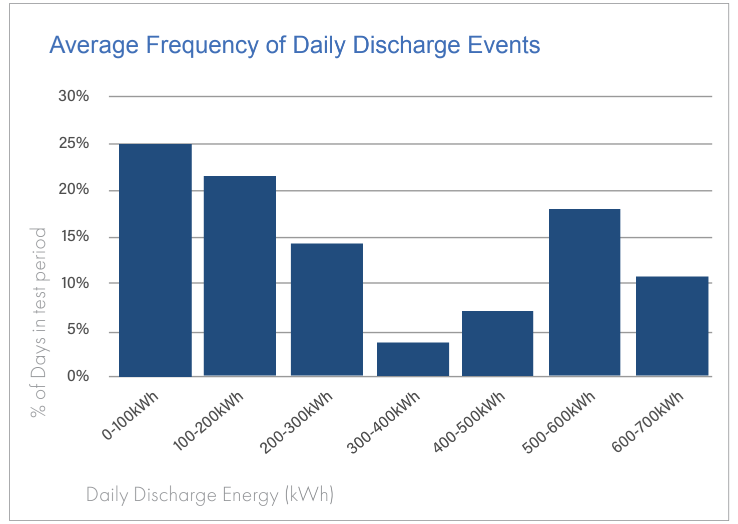
Graph 3

Average discharge performance

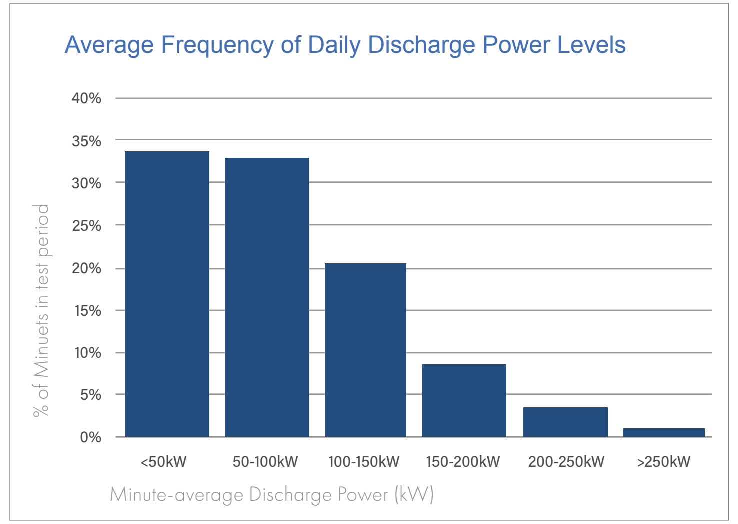
Peak discharge rates in excess of 300kW have been delivered. Due to the operating modes used, EnergiVault® has seen a wide variety of discharge rates, providing flexible cooling support. Discharge rates averaged across all test data, is shown in Graph 4 below.

Typical discharge rates have been <150kW, reflecting chiller optimisation support, with EnergiVault® acting as first or second chiller to avoid chiller cycling. The higher discharge rates reflect EnergiVault® providing peak demand support where facility demand was significantly in excess of chiller capacity, in times of higher ambient temperature and humidity, or with shutdown of core chillers requiring EnergiVault to provide complete facility cooling.

In terms of total daily discharge, Graph 5 below shows the averaged frequency of different daily discharge rates.



Graph 4



Graph 5

Discharge rates of less than 300kWh typically relates to chiller optimisation, with EnergiVault® providing cycling demand. In such mode, it has also been a requirement that the battery always retains a proportion of its charge, to act in uninterruptible cooling mode, meaning it is always available in case of chiller failure. Higher daily discharge rates equate to peak demand support, when existing chillers are unable to cope with cooling demand, or shut-down of core chillers, with EnergiVault® providing supplementary or total cooling. In this mode the need for uninterruptible cooling is less critical, as the peak support is already preventing operational shutdown.

Substantial savings

"Our compressors run to a minimum of 25%. Four chillers, four compressors; if we've got one going that's 25%. We can't slow it down any more than that so we're always going to be using that energy, whether we need to or not.

In the colder months, instead of bringing that compressor on, EnergiVault® takes that small load for us during the day.

If we don't have to fire up our chillers and can use the EnergiVault® instead, that should bring substantial savings."

Stuart Munro
Head of Facilities
Quotient Sciences

ILLUSTRATIVE OPERATING MODES AND OPTIMISATION

The more regular cycling of discharge in the later period corresponds to chiller optimisation, with EnergiVault® discharging to act as first or second chiller, so avoiding inefficient cycling of existing chillers.

As noted previously, EnergiVault® has four typical modes of operation. Each have intrinsically the same characteristic of delinking energy supply away from energy demand; the different profiles simply reflect different rates and duration of discharge.

Choice of modes is influenced by:

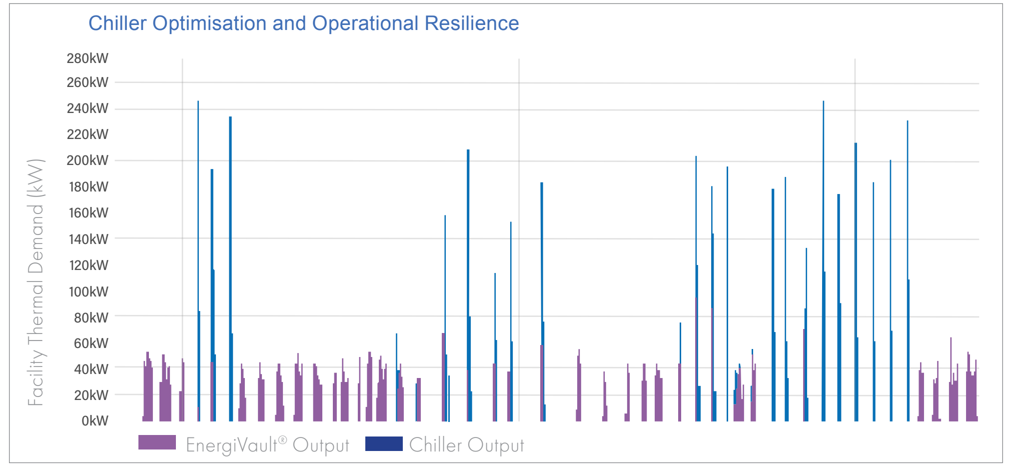
- **Economic and carbon returns** – charging in times of low-cost or low-carbon electrical supply, discharging to avoid high-cost or high-carbon supply. Typically characterised by load-shifting and chiller optimisation modes
- **Operational resilience** – providing a store of energy to ensure operations can continue unhindered during periods of insufficient supply from core systems (such as breakdown, maintenance, inadequate capacity). Can also be used as a supplementary chiller, with low electrical input, where site incoming supply is inadequate. Typically characterised by peak demand support and uninterruptible cooling modes.

Each of the modes of operation, with the exception of load-shifting, have been applied during the test period.

Examples of each mode, again taken from the Customer Dashboard but showing a single day profile, are shown here in Graph 6.

Chiller optimisation

When chillers are operating efficiently (red profile), EnergiVault® remains in battery mode. As sub-optimal chiller performance is encountered, EnergiVault® can provide cooling demand (blue profile) to avoid inefficient chiller cycling.



Graph 6

Peak demand support - Graph 7

In this example, for the majority of time there is a steady cooling demand, which is met by existing chillers. When a surge in demand is experienced, EnergiVault® is able to provide top-up cooling. Without this support, temperatures would rise, risking shutdown.

Uninterruptible cooling supply - Graph 8

As a back-up battery, EnergiVault® is able to retain thermal energy for significant periods of time.

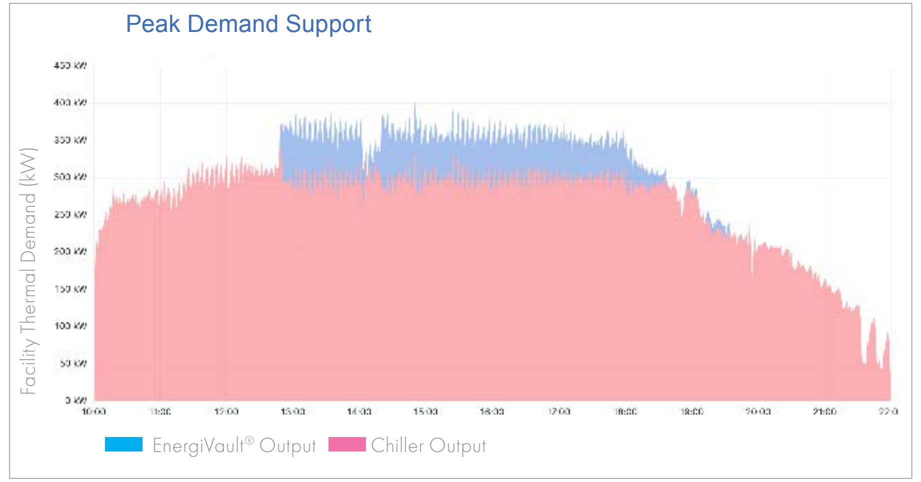
When existing chillers experience planned or unplanned downtime this store can be accessed to provide the total cooling demand.

Optimisation

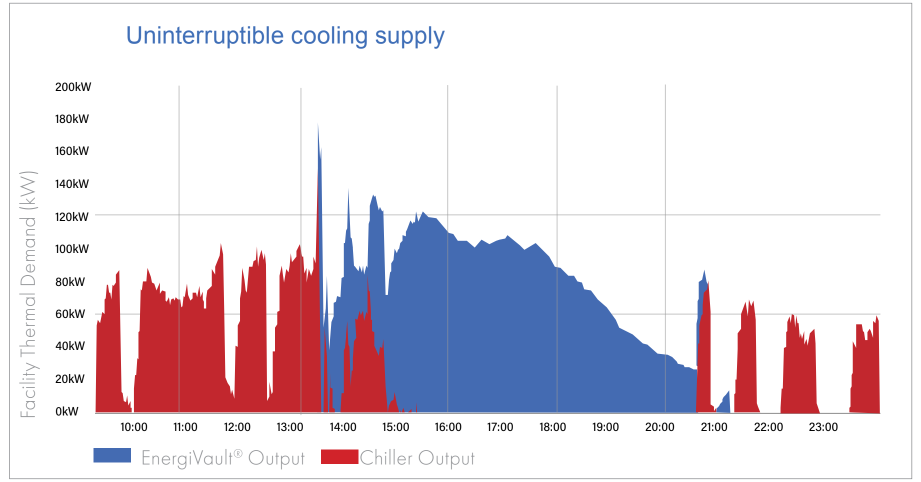
The purpose of optimisation is to leverage weather, energy and efficiency forecasts – alongside tariffs and customer operational requirements – in order to decide:

- What is the value from each operating mode (mitigating facility shutdowns, reducing grid import costs, using surplus renewable energy, improving chiller efficiency etc)?
- How much energy is needed to reserve for each operating mode?
- When is it cheapest to charge EnergiVault® (avoiding network constraints)?

Most EnergiVault® sites will have variable demand, with opportunities to deliver value across multiple operating modes and cost-effective variable tariffs. In these cases, the proprietary optimising software can unlock significant additional value.



Graph 7

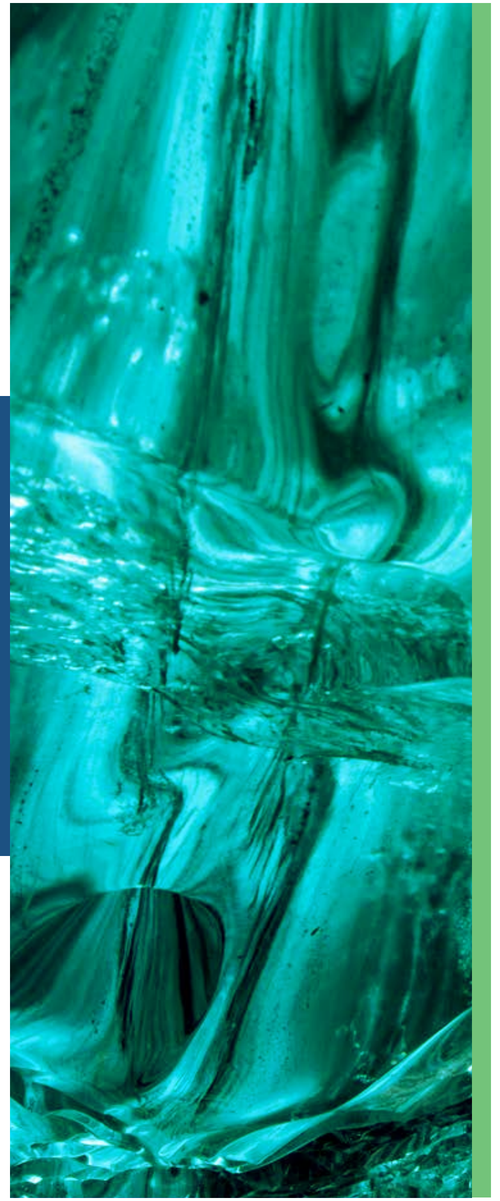


Graph 8

Off-peak benefits

"If we have an off-peak tariff, we can charge up the EnergiVault® at night and during the day during the winter months we don't have to bring our chillers online at all. We are using this cheaper energy source that we charged up overnight and we're drawing down on it throughout the day".

Stuart Munro
Head of Facilities
Quotient Sciences



More to come

"I was fairly nervous at first about the EnergiVault® coming in because this site is my responsibility and if we messed up the cooling it could bring down the business.

But actually, the communication has been great and there's been zero negative impact to us.

It's been a really fun, good journey and there's more to come."

Stuart Munro
Head of Facilities
Quotient Sciences

Bob Long showing ice slurry at the open day

REFERENCES

The Montreal Protocol
An international agreement was made in 1987 designed to stop the production and importation of ozone depleting substances to reduce their concentration in the atmosphere, to protect the earth's ozone layer.

The Paris Agreement
A legally binding treaty on climate change. Its goal is to limit global warming below 2°C compared to pre-industrial levels.

UN Environment Programme
Responsible for coordinating responses to environmental issues within the United Nations system.

International Energy Agency (IEA)
An autonomous intergovernmental organisation, established in 1974, that provides policy recommendations, analysis and data on the entire global energy sector.

The Department for Business, Energy and Industrial Strategy (BEIS)
A ministerial department supported by 46 agencies and public bodies bringing together responsibilities for business, industrial strategy, science, innovation, energy, and climate change. Through a chilled water network to cool buildings. (BEIS restructured in 2023, with four new departments including a Department for Energy Security and Net Zero).

National Grid ESO
National Grid ESO is the electricity system operator for Great Britain.

The Birmingham Energy Institute (BEI)
BEI is developing and applying the technological innovation, original thinking and new ways of working required to create sustainable energy solutions and support the regional, national and global transition to a zero carbon energy system.

The Institute of Global Innovation (IGI)
Part of the University of Birmingham. The IGI aims to inspire, support and deliver world-leading multidisciplinary research that addresses the world's most pressing challenges, including environmental pollution solutions and clean air.

The Carbon Trust
Formed in 1999 as part of the development of the Climate Levy, the Carbon Trust is an expert partner for businesses, governments and organisations around the world helping them decarbonise and accelerate to Net Zero.

The Green Cooling Initiative
An autonomous intergovernmental organisation, established in 1974, that provides policy recommendations, analysis and data on the entire global energy sector.

The Institute of Refrigeration
The Institute of Refrigeration (IOR) is an independent registered charity run for the public benefit with a membership of over 2200 individuals reflecting the diversity of the refrigeration, air conditioning and heat pump sector (RACHP).

Distribution Network Operator (DNO)
DNOs are licensed companies that own and operate the network of cables, transformers and towers that bring electricity from the national transmission network to businesses and homes in the UK.

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