D4.1: International Benchmark of Cooling Demand Response Programmes

CoolDown: SIF Discovery Project

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Executive summary

This report is an output for CoolDown, an Ofgem-funded Strategic Innovation Fund (SIF) Discovery project exploring the impact of space cooling on distribution network capacity and the potential need for cooling demand response (DR). The report summarises findings from work package four of CoolDown: evaluating cooling DR. It:

- Places projected increases in UK space cooling demand into a global context.
- Defines DR and categorises various DR mechanisms.
- Identifies and analyses international cooling DR programmes, extracting key learnings which can be applied to a UK context.
- Evaluates the potential suitability of different DR mechanisms for the UK.
- Outlines complementary options to DR to reduce building cooling demand.

Insights from this report will inform the development of future cooling DR initiatives in the UK. Key findings are summarised below.

Cooling demand is expected to grow worldwide, including in the UK.

Space cooling demand has surged worldwide in recent decades and is expected to continue growing. Two thirds of homes could have air conditioning (AC) by 2050. Whilst the USA and Japan already have >90% AC penetration rates, adoption rates in China and India are soaring.

A key driver of space cooling growth is rising temperatures due to climate change. The UK is no exception to this. Cooling already accounts for 10% of the UK's electricity demand. It is dominated by commercial spaces like offices and retail outlets. With 30% more uncomfortably hot days expected in the UK at 2°C of global heating, demand for cooling systems is expected to increase. Commercial adoption rates will rise. 5-32% of homes are projected to adopt AC by 2035.

A 32% adoption rate could increase summer peak loads by 7 GW, leading to potential overloading of distribution substations. Avoiding this requires a range of supply and demand-side solutions, one of which is DR.

DR programmes can broadly be categorised as price-based or incentive-based.

DR programmes encourage energy consumers to shift their usage away from times of peak demand and/or low supply. They can be grouped into two main categories - price based programmes and incentive based programmes. Price based programmes leverage price signals to encourage customers to adjust their consumption patterns. Examples include peak time rebates and real-time pricing, time of use and critical peak pricing tariffs. Incentive based programmes provide direct payments to consumers who shift their demand when prompted. Examples of retail market incentive-based programmes include direct load control, interruptible load and demand bidding/buyback.

Cooling DR programmes are most prevalent in North America and Australia.

Cooling DR typically incorporate at least one of cycling cooling technologies on and off, adjusting temperature setpoints and shifting cooling operations to off-peak hours to address peak demand in summer months.

Our international benchmark identified 12 cooling DR programmes and trials across North America, Australia, and the Middle East, as illustrated in Figure 1. Programmes are most prevalent in North America, where cooling is ubiquitous.

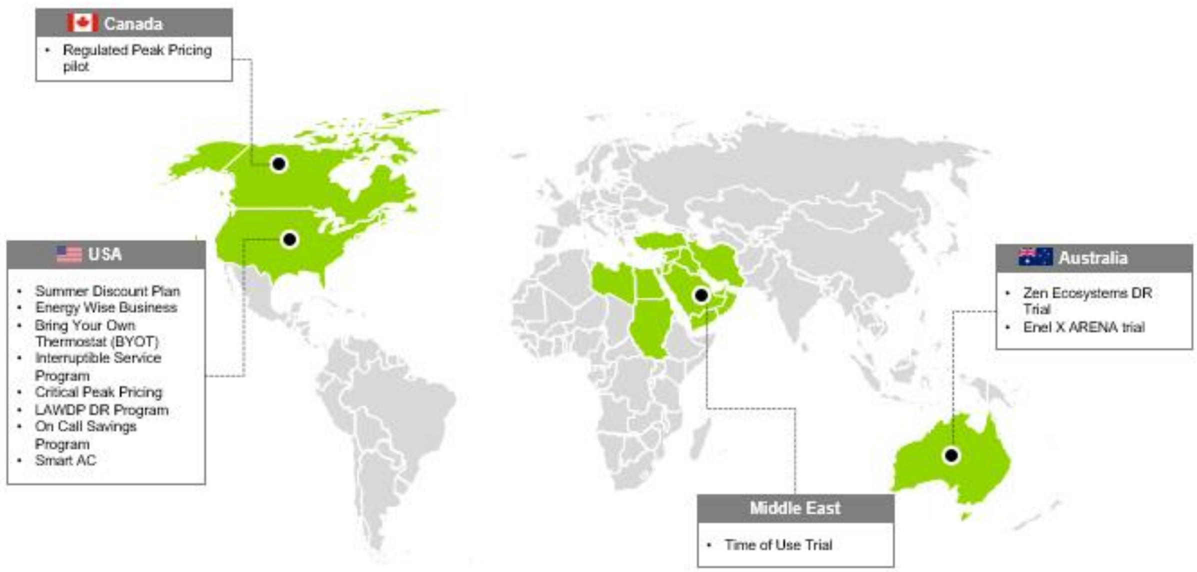

Figure 1. Map showing the geographic distribution of the reviewed cooling DR programmes and trials.

We assessed each programme's key characteristics such as the eligible cooling technologies, target customers, programme design, event timing, notice period and incentive approach. We also deep-dived into four programmes representing a spectrum of programme types to extract more detailed insights. We grouped key learnings from the benchmarked programmes into three categories: programme design, customer offerings and recruitment, and customer preference.

Programme design differs across almost every programme. There are a range of incentive mechanisms, event timings and notice periods.

- A direct load control incentive-based approach is the modal approach. This saw utilities paying customers for being able to remotely control their cooling.
- Bill credits are the most common form of incentive structure. Some programmes adopt price-based approaches. Trials often use sign-up bonuses.
- DR event timings differ depending on when in the day the programme's jurisdiction experienced peak demand.
- 4-6 hours is the most common event duration. 6 hours is the maximum length.
- Notice periods vary by programme, though the majority give two hours or less.
- More programmes target commercial customers than residential.

Providing optionality increases customer recruitment.

- Designing a programme that enables customers to opt out allows customers to have more control over their own comfort.
- In some programmes, the utility covers the cost of installation of devices like thermostats needed to make customers eligible to participate. This removes the burden from the customer and increases the participant pool.
- Some programmes allow customers to choose between controlling their own devices or allowing them to be directly controlled.
- In the Enel X ARENA trial, sites with direct load control performed better on average against customer-controlled sites.

Well-designed programmes give customers time to plan for DR events and may even action events without participants even noticing.

- Giving customers sufficient notice of events helps them plan accordingly. This is especially important for price-based programmes.
- Restrictive parameters such as a defined cycle percentage or short response time could restrict customer participation.
- If designed well, direct load control of cooling devices can occur without participants even noticing when there has been a DR event.

Market precedent, expected cooling technologies and thermal comfort limits will all impact the design of potential future cooling DR programmes in the UK.

All price-based mechanisms except for critical peak pricing tariffs have precedent in the UK, either through trials or business as usual products. Direct load control and interruptible load incentive-based set ups also exist in the UK. Residential-targeted DR programmes will need to be tailored to split system ACs, expected to be the key cooling technology for existing home retrofits. No benchmarked programme focused on this technology. The heating and cooling technology mix in future new build homes remains uncertain. Central AC is already prevalent in the UK's commercial buildings, so existing international programmes could be directly tailored for UK use cases. Across all UK building types, around 24°C is the typical upper temperature limit for thermal comfort; DR programmes should be designed based on this.

Passive cooling, dynamic solar shading and pre-cooling can all complement or reduce the need for cooling DR.

Passive cooling design approaches minimise heat gain during warm periods. Ground-source heat pumps can also be used to provide passive cooling, transferring building heat to the significantly cooler ground. Pre-cooling has been incorporated into several cooling DR programmes, but its effectiveness varies depending on the thermal properties of the building, for instance how well insulated it is.

Introduction to CoolDown

As the United Kingdom (UK) warms due to climate change, homeowners and businesses are more likely to turn to space cooling. Despite modelling suggesting increasing cooling demand, cooling demand is currently poorly accounted for in distribution network planning. Cooling's potential to offer flexibility during periods of network stress has not been considered.

CoolDown is the first project in the UK to consider this potential, exploring the impact of cooling on distribution network capacity by producing improved cooling adoption and demand projections. The project is also developing commercial models to incentivise and unlock flexibility from space cooling. This will reduce or defer required network reinforcement and optimise value for consumers.

CoolDown is a Strategic Innovation Fund (SIF) Discovery project funded by Ofgem. The project is led by Electricity North West Limited (ENWL), supported by project partners Guidehouse and University College London Consulting (UCLC).

Scope of this report

This report is the output of work package four of CoolDown: evaluating cooling demand response (DR).

The report offers a high-level assessment of cooling demand response programmes, focusing on their design and their suitability to the UK. By benchmarking international programmes and providing real-world case studies, this report aims to extract valuable insights and learning that can be adapted for creating future cooling DR programmes in the UK.

The report is structured into four sections:

Context: Cooling demand and DR

- Summarises increasing global demand for space cooling, covering key drivers and current and projected figures.
- Defines DR and explores various DR mechanisms, including price-based and incentive-based programmes.

DR benchmarking

- Outlines our approach to identifying and analysing international cooling DR programmes.
- Compares the design of various international cooling DR programmes.
- Identifies key lessons learned and best practices from benchmarked programmes.
- Evaluates the potential suitability of different DR mechanisms to the UK at a high level, setting the scene for more detailed potential UK cooling DR programme designs in CoolDown deliverable D5.1.

Complementary options to cooling DR

- Explores complementary options to DR for reducing building cooling demand such as solar shading and passive cooling.

Case study deep dives

- Dives deeper into specific cooling DR programmes via dedicated case studies. Each case study provides insights into the programme design, eligibility criteria, DR event details, and mode of incentive.

Context: cooling demand and DR

Overview of cooling demand

The demand for space cooling has surged worldwide in recent decades, driven by a range of factors such as urbanisation, population growth and rising temperatures due to climate change. Demand for space cooling has grown faster than any other energy end use in buildings globally, more than tripling since the 1990s. Roughly 2 billion air conditioning (AC) units worldwide account for approximately 20% of global electricity use.

As temperatures continue to rise, cooling demand is only expected to increase. The IEA estimates that two thirds of households worldwide could have AC by 2050[1]. Some countries already have very high AC penetration rates, like the USA (>90%) and Japan (>91%). Others are expected to grow rapidly over the coming decades, such as China and India.

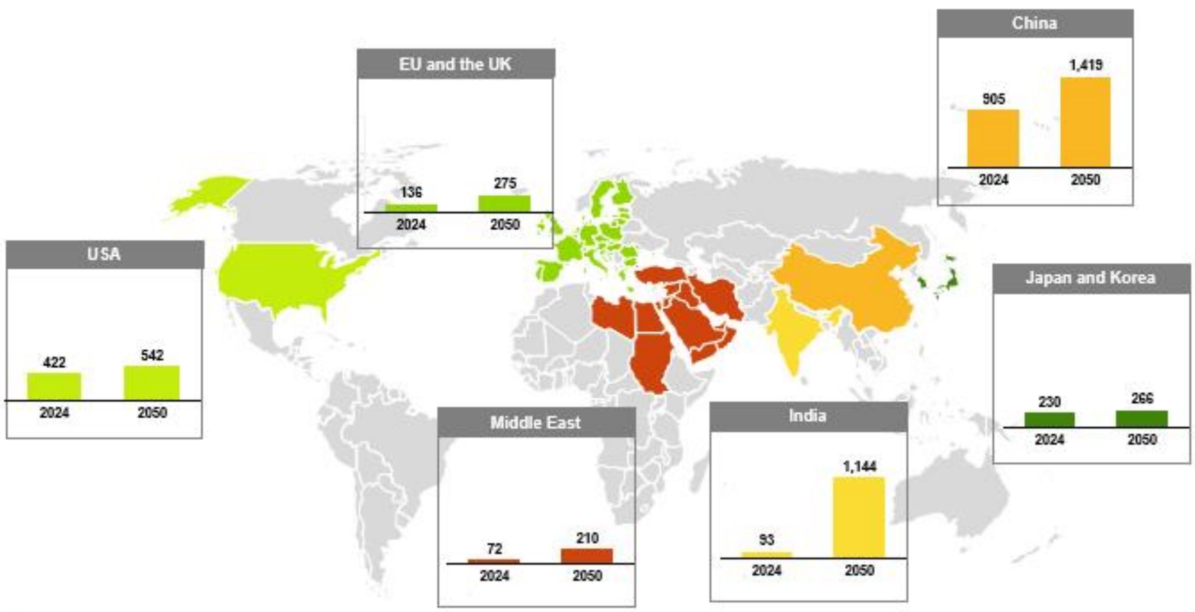

Figure 2. Current and forecasted 2050 global AC stock for selected countries and regions (in millions of units)[1].

UK cooling demand

The effects of global warming are also increasing the UK's need for space cooling. Heat waves like summer 2018's, in which the mean air temperature from June to August was the joint highest on record, are now 30 times more likely to happen due to climate

[1] IEA, The Future of Cooling, 2018

change[2]. July 2022 saw temperatures exceed 40°C for the first time, smashing the previous UK record of 38.7°C set in 2019[3].

A 2016 study found that cooling demand already accounted for 10% of total UK electricity demand[4]. Current cooling demand is dominated by commercial buildings[5]; with 65% of office spaces and 30% retail spaces having AC[6].

However, space cooling demand is expected to increase in both residential and commercial sectors. Estimates suggest that up to 20% of homes already experience overheating during an average summer[7]. At 2°C of global heating, there will be 30% more uncomfortably hot days in the UK[8], with over a third of English homes at risk of overheating in future[9]. Space cooling will therefore become more widespread in the residential sector. 5-32% of UK homes are forecast to adopt AC by 2035[10]. The estimated spread demonstrates current uncertainty about adoption rates.

This projected increase in cooling demand will increase energy consumption. A 32% domestic adoption rate could increase UK-wide summer peak loads by 7 GW[9]. This could overload summer-peaking distribution substations, necessitating costly reinforcements. Addressing this challenge mandates a range of demand and supply side solutions, one of which is DR.

Overview of DR

DR is a flexibility approach that balances electricity demand by encouraging or mandating consumers to shift their electricity usage away from times of peak demand and/or low supply.

As variable renewable electricity sources and electrified energy end uses proliferate, DR is becoming a more important tool to ensure grid stability and reliability. In 2020, available global DR capability was less than 100GW and represented around 2% of total flexibility[11]. Since then, numerous markets have expanded their DR capacity. The United States has perhaps the most developed DR landscape. In 2022, it recorded over 30GW of potential peak demand savings across its various DR programmes. With over 10 million customers, total energy savings for that year were almost 1,300GWh[12].

Most DR programmes operate through monetary instruments like variable electricity prices (price-based) or payments for shifting usage (incentive-based)[13].

[2] Met Office, Climate change continues to be evident across UK, 2021
[3] Met Office, UK prepares for historic hot spell, 2022
[4] DECC, Study on energy use by air-conditioning: Final Report, 2016
[5] BEIS, Cooling in the UK, 2021
[6] As 5.
[7] Brimicombe et al., Heatwave: an invisible risk in UK policy and research, 2021
[8] Miranda et al., Change in cooling degree days with global mean temperature rise increasing from 1.5 °C to 2.0 °C, 2023
[9] Resolution Foundation, It’s getting hot in here, 2023
[10] UKERC, Domestic air conditioning in 2050, 2020
[11] IEA, DR Activity, 2020
[12] EIA, DR – yearly energy and demand savings
[13] IEA, DR overview

Price-based programmes leverage price signals and tariffs to encourage consumers to adjust their consumption patterns. Price-based programmes can be divided into four categories:

- **Real-time pricing tariffs**: rate structure in which energy price per kWh changes hourly or half-hourly for the consumer, for instance by tracking wholesale prices. Also known as dynamic or spot pricing.
- **Peak time rebates**: customers are credited or provided an incentive (typically monetary) for reducing their load consumption during peak hours.
- **Time of use tariffs**: rate structure in which the utility charges different electricity prices to customers at different times of day e.g., off-peak rates, on-peak rates, night-time rates, etc.
- **Critical peak pricing tariffs**: rate structure in which the utility spikes electricity prices during a narrowly defined peak period (e.g., two-hour weekday evening peak). These peak prices are predetermined and can be up to ten times higher than normal rates.

Incentive-based programmes provide direct payments to consumers who participate in DR events by shifting their demand when prompted. These programmes can be split across the wholesale and retail markets.

There are three typical programme types within the **retail market**:

- **Direct load control**: mechanism in which customer appliances are directly controlled by a utility or other third-party aggregator and are turned off or adjusted to a lower energy consumption (e.g., increasing thermostat setpoint to reduce cooling energy usage).
- **Interruptible load**: customers agree for a utility to turn off the power supply to a part of their load during peak periods in exchange for monetary compensation.
- **Demand bidding/buyback**: customers offer bids to reduce their load based on electricity market prices; programme is usually offered to larger consumers (> 1MW), although smaller consumers could participate via an aggregator.

There are also three programme types within the **wholesale market**:

- **Ancillary services**: consists of several speciality services that are typically provided by generators to ensure safe operation of the transmission grid. For example, energy users may be paid to provide frequency control by reducing demand to keep the grid operating.
- **Emergency DR programme**: incentive payments are provided to customers for load reduction achieved in response to an emergency on the transmission system.
- **Capacity market programme**: customers offer load reductions as system capacity to replace conventional generation sources during peak demand periods; incentives are usually upfront reservation payments.

Figure 3 provides an overview of these main DR programme categories.

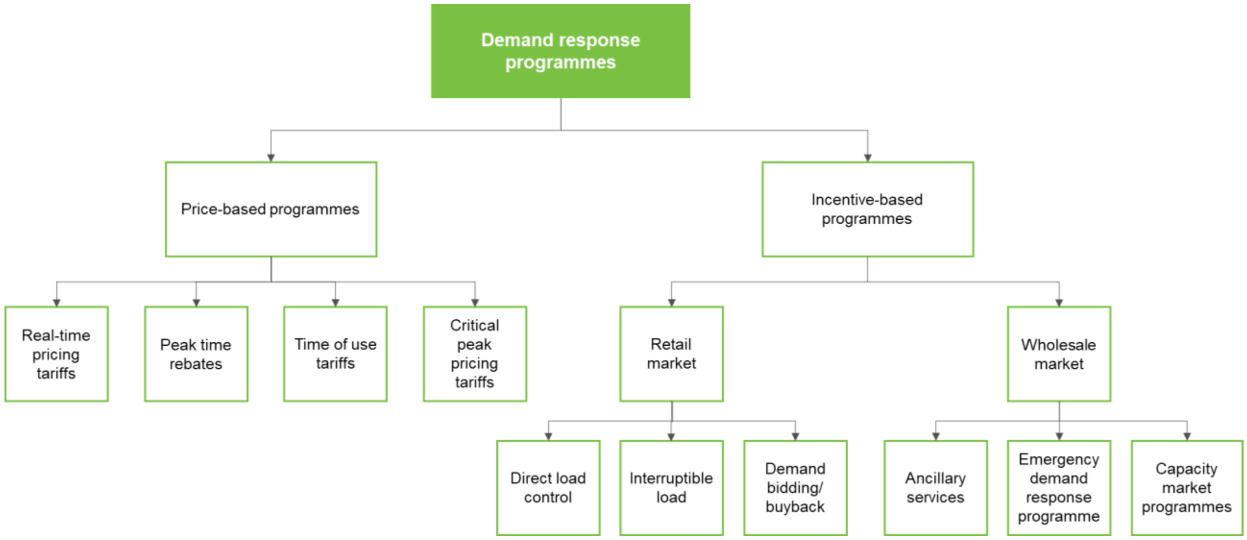

Figure 3. Flowchart categorising DR mechanisms[14]

Whilst retail market DR programmes can focus on any type of energy consumer, wholesale market DR programmes tend to focus on large generators and industrials. As CoolDown is focused on residential and commercial energy users, this report's benchmark concentrates on price-based programmes and retail market incentive-based programmes.

[14] Adapted from Alasseri et al., Conceptual framework for introducing incentive-based DR programs for retail electricity markets, 2017.

DR benchmarking

Overview of cooling DR

Cooling DR is tailored to addressing peak demands arising from space cooling, such as AC. These peaks generally occur during the summer months. Cooling DR programmes typically incorporate one or more of the following:

- Cycling cooling technologies on and off.
- Adjusting temperature setpoints.
- Shifting cooling operations to off-peak hours.

Methodology and framework

We analysed existing cooling DR programmes utilising three steps:

1. Gathered a pool of existing cooling DR programmes and trials. We focused on hotter climates with established DR capabilities, like North America and Australia, or those in pilot phases like the Middle East.
2. Developed a framework for analysing each DR programme. This included basic programme details like eligible technologies, programme design and DR event details, as well as programme coverage and impacts for selected programme deep dives.
3. Analysed the identified cooling DR programmes using the framework, including deep dives for selected programmes. Assessed suitability of different programme types to the UK.

We gathered the following characteristics of each existing cooling DR programme or trial as part of the analysis framework:

- **Programme:** programme/trial name.
- **Organisation:** who runs the programme/trial.
- **Jurisdiction:** where the programme/trial is based.
- **Eligible technology:** which cooling technologies (e.g., AC, reversible heat pumps (HP), etc.) are eligible to participate in the programme/trial.
- **Target customer:** which customers are targeted or eligible for the programme/trial (e.g., residential, commercial).
- **Design:** which category of DR programme the programme/trial fits within. Brief description of how the programme/trial is set up.
- **Event timing:** when DR events can be called (e.g., which months of the year, what time of day, and for how long).
- **Notice period:** how much notice is provided to the programme/trial participants prior to the start of DR events.
- **Incentive:** how participating customers are rewarded or reimbursed for their participation in DR events as part of this programme/trial. These could be fixed

payments or variable, for instance dependent on kW capacity, kWh of energy, or percentage cycling level.

Summary of international benchmarks of cooling DR programmes

We identified 12 cooling DR programmes and trials across North America, Australia, and the Middle East, as illustrated in Figure 4.

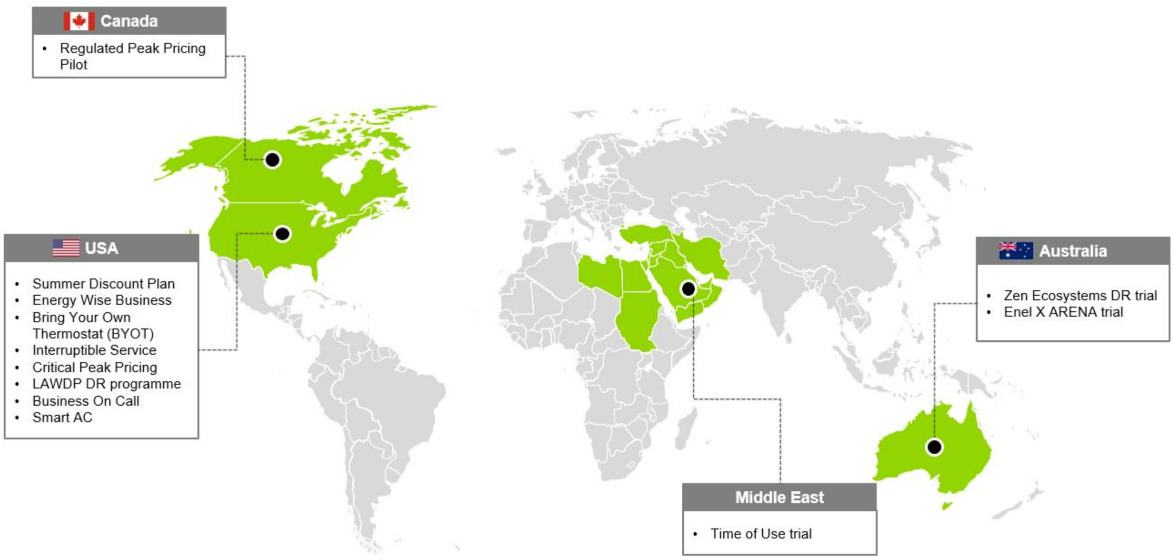

Figure 4. Map showing the geographic distribution of the reviewed cooling DR programmes and trials.

Table 1 details the key characteristics of each DR programme. There is a mix of:

- Eligible technologies, largely focused on AC or technology agnostic.
- Residential and commercial focused programmes.
- Notice periods ranging from day ahead to real time.
- Mechanism types, including direct load control, critical peak pricing, time of use, peak time rebates and interruptible load.
- Event durations from 1-6 hours.
- Fixed and variable incentives.

Table 1. Properties of selected international cooling DR programmes and trials.

No	Programme name	Organisation and jurisdiction	Eligible technology	Target customer	Design	Event timing (Time of day, duration)	Notice period	Incentive
1	**Summer Discount Plan (SDP)**	Southern California Edison (SCE) – California, USA	AC	Residential/ commercial	**Direct load control** – utility-owned device controls AC demand by cycling or turning them off	June to October, anytime, any day, up to 6 hours	Real time	**Variable** – customer receive bill credits based on selected offerings (Up to $145 for commercial and $160 for residential, annually per unit)
2	**Energy Wise Business**	Duke Energy – South Carolina, USA	AC or electric heat pumps (HP)	Commercial	**Direct load control** – utility installs new Wi-Fi- enabled thermostat/switch to cycle customer's AC or HP compressor load	May to September, any time, any day, up to 4 hours	At least 4 hours in advance (i.e., >=4 hours)	**Variable** – customer receive bill credits based on the cycling percent level (up to $135 annually per unit)
3	**Bring Your Own Thermostat (BYOT)**	Orange & Rockland – New York, USA	Central AC	Residential or small business	**Direct load control** – utility makes brief, limited adjustments to central AC settings via an approved thermostat	May to September, 11:30am to 11pm, weekdays, up to 4 hours	Real time	**Fixed** – one-off payment of $85 for enrolling
4	**Interruptible Service**	Tucson Electric Power – Arizona, USA	Technology-agnostic	Commercial (>3000kW demand)	**Interruptible load** – utility commences service interruptions on customer capacity that has been enrolled into the programme	May to September, any time, any day, up to 6 hours	30 minutes	**Variable** – based on interruptible kW capacity and company's 'Market Value Capacity Price' (MVCP)
5	**Critical Peak Pricing**	SCE – California, USA	Technology-agnostic	Commercial and industrial	**Critical peak pricing** – tariff-based structure where utility sets high prices (3-5X more than average) on hottest afternoons	June to September, 4pm – 9pm, any day, 5 hours	Day ahead	**Variable** – bill credits during the summer months (June 1 - September 30)
6	**DR programme**	Los Angeles Department of Water and Power – California, USA	Technology-agnostic	Commercial	**Peak time rebates** – participants initiate their curtailment procedure during the DR event to achieve a pre-determined load reduction	June 15 to October 15, 1pm – 6pm; any day, at least 4 hours	Day ahead or 2 hours	**Variable** – two kinds of payment: Availability payment ($8/kW for day ahead and $12/kW for 2-hour notice) and utilisation payment ($0.25/kWh)

No	Programme name	Organisation and jurisdiction	Eligible technology	Target customer	Design	Event timing (Time of day, duration)	Notice period	Incentive
7	**Business On Call**	Florida Power and Light – Florida, USA	AC	Commercial	**Direct load control** – utility occasionally cycles customer's ACs during peak periods	April to October; 3pm – 6pm, at least 4 days a week, up to 2 hours a day	Real time	**Variable** – summer bill savings in the based on $2 per ton[15] of AC load, whether the programme is activated or not
8	**Zen Ecosystems DR trial**	Zen Ecosystems – Victoria, Australia	Centralised cooling system (Small commercial) and HP (residential)	Small commercial/ residential	**Direct load control** – utility cycled customer's AC remotely through company proprietary system	4pm – 6pm on trial days, 2 hours	60 minutes	**Fixed** – customers received a free Zen Air device and access to Zen HQ web and mobile applications
9	**Enel X ARENA[16] trial**	Enel X – New South Wales and Victoria, Australia	Technology-agnostic	Commercial and industrial	**Direct load control/ Peak time rebates –** customer or utility commence customised load reduction process when a DR event is called	November 2019 and 2020; 2pm – 4pm on trial days; 2 hours	10 minutes	**Variable** – two pricing structures to customers: availability (based on customer's daily availability for responding to an event) and energy payments per MWh for energy delivered
10	**Time of Use trial**	Middle Eastern Company (confidential)	Technology-agnostic	Commercial and industrial	**Time of use –** price-based programme during summer in which peak rate was 3-4X higher than off-peak rates	June to September, 4pm – 10pm, every day, up to 6 hours	Participants notified at the beginning of the trial	**Variable** – customers receive incentives equal to the amount of energy saved i.e., incentive = standard bill – time of use bill
11	**Smart AC**	Pacific Gas & Electric Company (PG&E) – California, USA	AC	Residential electric customers	**Direct load control** – utility cycles customers AC during peak cooling periods	June to October, 1pm – 6pm, for at least 4 hours, one per day	At least 2 hours before	**Fixed** – one-time compensation ($50 for Smart AC and $75 for Smart Thermostat)
12	**Regulated Peak Pricing Pilot**	London Hydro – London, Canada	Technology-agnostic	Mostly residential	**Critical peak pricing** – price-based trial where utility set high prices (~$0.6/kWh – almost 10X the off-peak rates) during peak events to encourage customer turn down	5pm - 8 pm, for 1 hour	15 minutes	**Fixed** - $100 incentive for participation ($25 at enrolment, $75 at end of pilot)

[15] A ton is a measure of the cooling capacity of the AC i.e., how much heat it can remove from the building in one hour.
[16] Australian Renewable Energy Agency

Impact of cooling DR programmes

All 12 cooling DR programmes and trials were implemented by utilities to achieve certain energy-related impacts, typically reducing cooling load during peak periods. To deliver this, the utilities presented monetary incentives to customers which had associated cost impacts.

Energy impact – load reduction

Many cooling DR programmes have effectively reduced peak electricity demand during periods of high cooling consumption. Examples include:

- By the end of 2022, PG&E in California, USA recorded that they had signed up ~187MW of cooling load in the Smart AC programme, resulting in an aggregate impact of 19MW in savings[17].
- Also in 2021, SCE's California SDP one-hour DR event on the peak system day (20.8GW load) saw aggregate demand reduce by 166MW. Residential participants reduced demand by an average ~30% and commercial customers ~11%[18].
- In 2020, the statewide load impact of California's non-residential CPP programme was ~35MW, around 1.3% of the reference 2.7GW load[19].

The magnitude of peak load savings achieved in AC or HP-focused programme is largely dependent on the cycling level. For example, in the SDP, on average, load reduction impacts in the 100% cycling group were more than double the reduction achieved by the 50% cycling group.

Cost impact – customer earnings

Customers participating in cooling DR programmes can enjoy significant cost savings on their energy bills and other incentives. Across almost half of the cooling DR programmes benchmarked, bill credits are provided to customers as an incentive for reducing their load. For example:

- The Energy Wise Business programme provides bill credits of up to $135 per AC or HP unit, one year after enrolment.
- Both programmes offered by SCE (SDP and Critical Peak Pricing) also compensate their customers in form of bill credits.
- In 2022, customer incentives across all US DR programmes amounted to ~$1.12 billion, around $120 per participant[20].

17 Christensen Associates, Load Impact Evaluation: PG&E's Smart AC program, 2023
18 Demand Side Analytics, Program Year 2021 SCE Summer Discount Plan Impact Evaluation, 2022
19 Applied Energy Group, Statewide Load Impact Evaluation of California Non-Residential Critical Peak Pricing Programs, 2021
20 EIA, Electric Power Annual 2022

Key learnings

Learnings and best practices from these twelve cooling DR programmes can be summarised across three categories. As shown in Figure 5, these are programme design, customer offerings and recruitment, and customer preferences.

Figure 5. Categories of key learnings from the cooling DR programmes reviewed.

Programme design

- There are many ways of reimbursing customers for providing cooling flexibility, including various tariffs, bill rebates and per kWh payments. Sign up bonuses are also common for trials.
- Some cooling DR programmes (e.g., Energy Wise Business by Duke Energy, Summer Discount Plan by SCE) have a range of offerings targeted to customers with different load profiles. This increases the number of eligible cooling assets and therefore the potential load reduction.
- A one-off participation payment may be reasonable when customers have the autonomy to change their AC settings at any time.
- Although uncommon, in cases where the trial is not run by a utility like the Zen Ecosystems DR trial by Zen Ecosystems, partnering with an energy supplier offers access to customers' energy data for assessing performance.
- A degree of centralised thermal building control via thermostats or switches for customer cooling systems is often required for cooling DR programmes.
- Understanding the thermal inertia of buildings is very important in defining parameters for cooling DR programmes, particularly the optimal event duration. For example, in the Middle Eastern Time of Use trial, there were not a lot of opportunities for DR in commercial and residential spaces as the thermal inertia of the building was not suitable to maintain temperature for the duration of the DR event (6 hours).
- There is no clear pattern to cooling DR event timings. The time of day varies by programme. 4 to 6 hours is the most common event duration, though some programmes have 2-hour and 1-hour durations.
- Notice periods for customers also vary by programme, though the majority give two hours of notice or less. Event timings, durations and notice across the benchmarked programmes and trials are illustrated in Figure 6.

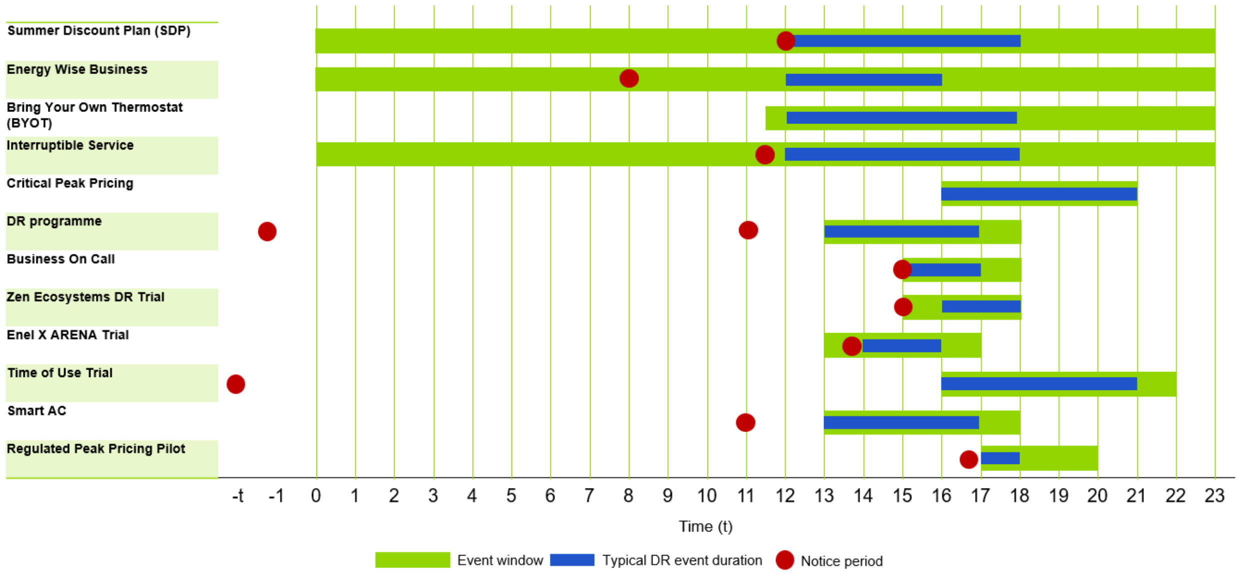

Figure 6. Diagram showing the event timing and notice period of selected cooling DR programmes[21].

Customer offerings and recruitment

- Designing a programme that enables customers to opt out allows customers to have more control over their own comfort.
- In some DR programmes like the Summer Discount Plan by SCE, the utility covers the cost of installation of devices like thermostats needed to make customers eligible to participate. This removes the burden from the customer and increases the participant pool.
- Some programmes allow customers to choose between controlling their own devices or allowing them to be directly controlled. In the Enel X ARENA trial, sites with direct load control performed better on average against customer-controlled sites.
- Participation-based incentives can prove ineffective, as in the Zen Ecosystems DR trial by Zen Ecosystems, where participation was lower than expected. The lack of education on the programme's objectives and feedback on individual customer impact resulted in customers losing interest.

Customer preference

- Sufficient notice given to customers, for instance day-ahead, could improve customers' ability to participate by planning their usage accordingly. This is

[21] Blue bar representing typical DR event duration, starts at 12pm when the event window starts before 12pm and starts at the start of event window when it is after 12pm; Notice period aligns with blue bar. -1 represents day ahead while -t represents that notification of event timings occurred at the start of the program. Event window refers to the time of day at which a DR event can occur.

particularly true of tariff-based programmes, where customers are penalised for not reducing their load by paying higher bills.

- Restrictive parameters such as a short response time or defined cycle percentage could restrict customer participation, particularly those with variable or unpredictable profiles.
- If designed well, direct load control of cooling devices can occur without participants even noticing when there has been a DR event.

Potential UK Suitability

The next CoolDown work package will focus on designing several potential cooling DR programmes which could be trialled in the UK. These will be summarised in deliverable D5.1. For now, this document provides a high-level view of which broad DR mechanisms could be suitable in a UK context.

UK precedent

For each mechanism, we identified whether or not there is a UK precedent for wider non-cooling DR. This is summarised in Table 2.

Table 2. DR mechanisms with UK precedent and example of use in the UK

DR mechanism	UK precedent	Example of use in UK DR programmes
Real time pricing	✓	Octopus Energy's ***Octopus Agile***[22] tariff, a first of its kind variable electricity tariff in the UK, where prices are updated every 30 minutes based on wholesale costs.
Peak time rebates	✓	OVO energy launched ***Power Move***[23] in late 2023, a programme that pays customers for using less energy between peak hours of 4 and 7pm
Time of use tariffs	✓	Octopus Energy's ***Octopus Cosy***[24] tariff**,** defines three different electricity tariffs within the day – a standard day rate, super cheap rates between off-peak periods and a peak rate.
Critical peak pricing	✕	There is currently no identified precedent for this in the UK market.
Direct load control	✓	This has been trialled for heating assets such as HPs in trials like ***EQUINOX***[25] and ***HeatFlex UK***[26]. No trials or programmes done for cooling assets.
Interruptible load	✓	***Flexible connections*** [27], offered by distribution network operators like ENWL represent a subset of interruptible programmes, where generation customers are provided with a constrained connection that is not guaranteed and can be disconnected within specific time periods.

[22] Octopus Energy, The 100% green electricity tariff with plunge pricing
[23] OVO Energy, Get paid to use less power, 2023
[24] Octopus Energy, Introducing Cosy Octopus, 2022
[25] National Grid, EQUINOX
[26] HeatFlex UK, Nesta
[27] ENWL, Flexible Connections

Technology

We also identified which international DR programmes may not be suitable for the UK based on technology eligibility.

Split system ACs are the current dominant technology in the UK. Over 75% of sales are single and multi-split units[28]. Split systems consist of an outdoor unit which dissipates heat absorbed from inside the building from one or more indoor units which cool the air inside individual rooms. For most existing residential buildings, heating is delivered through pipes and radiators. Since these cannot be converted to accommodate cooling, split systems are the most appropriate cooling retrofit for such homes, even if a heat pump is already installed for heating. We could not identify any DR programmes that specifically target split systems.

The direct load control cooling DR programmes reviewed often utilised central ACs, heating, ventilation, and air conditioning (HVAC) systems or reversible heat pumps. A central AC system cools air at a location and distributes this throughout the building via ducts or vents. HVAC systems, widely used across the USA, regulates indoor humidity and air quality as well as temperature. Finally, a reversible heat pump can both heat and cool a building using a refrigerant. A reversing valve allows the refrigerant to flow in different directions depending on whether heating or cooling is demanded.

Central AC and HVAC are already common in commercial UK buildings. They are currently rare in residential properties. It is uncertain how widespread reversible heat pumps and residential HVAC systems will be in the future. All options in the currently circulating Future Homes and Building Standards Consultation mandate that all new-build homes will need to be fitted with heat pumps from 2025[29]. If developers install air-to-air heat pumps instead of air-to-water, then a reversible set up with cooling would be possible.

How the technology mix develops as cooling demand increases in the UK will impact the level of DR potential and how that potential is accessed via a programme.

Thermal Comfort

Decreased cooling load during DR events increases temperatures in participating buildings. The thermal comfort of those within these building will help define the limits of cooling DR; if building inhabitants become too uncomfortable, they may ramp their cooling up again. A person in thermal comfort feels satisfied with the surrounding temperature, humidity, and air flow, thus contributing to overall wellbeing in indoor environment.

The UK Chartered Institution of Building Services Engineers (CIBSE) recommends operative summer temperatures of 23°C-25°C and ≤ 24°C for living rooms and bedrooms respectively[30]. It is similar for the UK's commercial buildings, where setpoints at or near 24°C are preferred[31,32].

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[28] BEIS, Cooling in the UK, 2021
[29] UK Government, The Future Homes and Buildings Standards: consultation, 2024
[30] CIBSE, Guide A, environmental design, 2006
[31] Lakeridou et al., The potential of increasing cooling set-points in air-conditioned offices in the UK, 2012
[32] Lakeridou et al., Imposing limits on summer set-points in UK air-conditioned offices: A survey of facility managers, 2014

Complementary options to cooling DR programmes.

Cooling DR is not the only way to reduce the impact of increased cooling demand on electricity grids. Alternative approaches focused on building design and energy efficiency can also be effective. Passive cooling, dynamic solar shading and pre-cooling all represent compelling complementary options to cooling DR strategies.

Passive cooling

Passive cooling is a building design approach that focuses on minimising heat gain during warm periods and increasing heat loss during cooler periods. This improves the indoor thermal comfort and reduces the need for energy consumption for space cooling.

Several passive cooling strategies exist, as summarised in Table . They are used as appropriate for different types of building.

Table 3. Definition of various passive cooling strategies

Passive cooling strategies	Description
Shading devices	Protecting the building from direct sunlight, overheating and glare by installing an additional component to a window and/or façade. This could be external (shutter, awnings, etc.) or internal (curtains, blinds, etc.).
Green shading and roofing	Strategically positioning trees and vegetation on the outside of a building to block out sunlight, thus reducing the need for cooling or heating.
Double glazing	Improving insulation by using two glass panes separated by a layer of gas for windows, rather than just one glass pane. Triple glazing uses three glass panes.
Solar reflective window tints	Using special films on windows to reduce the amount of solar irradiation and glare that enters a building.
Natural ventilation	Using natural airflow through building openings like windows and doors to circulate fresh air and remove excess heat from the building.
Roof painting	Applying reflective coatings or paints to the exterior surface of the roof to increase solar reflectance. This reduces heat absorption and glare.
Groundwater-based cooling	Ground-source heat pumps can provide passive cooling by transferring building heat to the significantly cooler nearby ground.

Simulation studies conducted across Europe indicate the potential of passive cooling strategies to reduce cooling demand. A Swiss study[33] estimated that night ventilation and window shading could result in an 84% reduction of 2050 cooling demand, including a 71% reduction from window shading alone. A 2022 Austrian study[34] found that shading was most effective cooling measure, resulting in up to 60% lower future cooling demand.

[33] Silva et al., Opportunities for passive cooling to mitigate the impact of climate change in Switzerland, 2022.
[34] Mayrhofer et al., Modelling the effect of passive cooling measures on future energy needs for the Austrian building stock, 2022.

Dynamic solar shading

Solar shading devices on windows can be roller blinds, venetian blinds, roller shutters or awnings, as illustrated in

Figure *7*. These devices are passive cooling measures but when automated using smart controls, they can be considered as an active, smart energy efficiency measure. The smart controls enable the shading devices to automatically respond to weather elements like temperature and solar irradiation and interact with cooling technologies like HVAC.

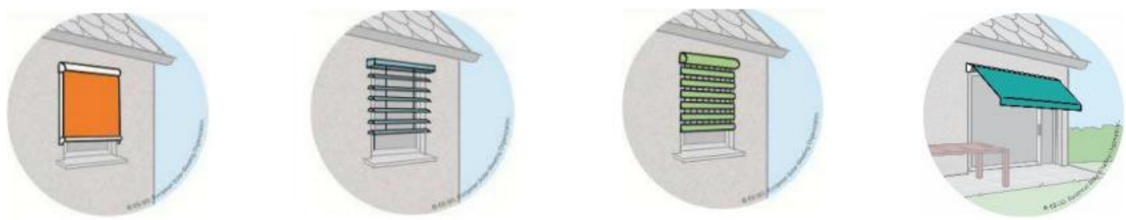

Figure 7: Different types of solar shading devices on windows[36]

Dynamic solar shading devices can mitigate future overheating of buildings and reduce the expected increase in cooling energy use. A 2021 study[35] found that dynamic solar shading could save up to 60% of electricity used for space cooling in the European Union (EU) by 2050 and reduce GHG emissions by up to ~100Mt of cumulated CO_2 equivalent emissions between now and 2050.

Pre-cooling

Pre-cooling prevents overheating and lowers cooling energy consumption by setting the indoor air temperature in a room or building to several degrees below its normal cooling setpoint during off-peak hours.

The impact of pre-cooling strategies has been demonstrated in various studies. In a US study conducted on a ~7,500sqm office building, precooling reduced peak cooling loads by 20-30% on hot days[36]. Some DR programmes incorporate pre-cooling into their design. For example, in the Australian Zen Ecosystems trial[37], commercial buildings were pre-cooled for 40-60 minutes prior to the start of the DR event by adjusting HVAC setpoints 3°C cooler than usual. Once the DR event commenced, the AC setpoint was adjusted to be 3°C warmer than usual (i.e., 6°C warmer than the pre-cooling setting).

The ability of pre-cooling to successfully shift demand out of peak hours is dependent upon several building characteristics, including the building's thermal mass. For example, although pre-cooling strategies were considered in a time of use pilot in the Middle East, the thermal inertia of most participating buildings was not sufficient to contain the cooler air for the entire 6-hour on-peak window.

[35] European Solar Shading Organisation, Solar shading, 2021
[36] Berkeley Lab, Pre-cooling and DR Tool development, 2007
[37] Zen Ecosystems, Project performance and knowledge sharing report, 2019

Case study deep dives

This section provides more detailed case studies for four of the benchmarked cooling DR programmes. These four programmes represent a broad spectrum of programme types, from target customers and load control mechanisms to incentive types and event durations.

The four programmes covered are:

- PG&E's Smart AC, a direct load control programme targeting residential customers.
- London Hydro's Regulated Peak Pricing, a customer controlled critical peak pricing pilot that targeted residential customers.
- Duke Energy's Energy Wise Business programme, a direct load control programme targeting commercial customers.
- Tucson Electric Power's Interruptible Service programme, an interruptible load programme that targets non-residential customers.

Each deep dives provides more depth on the programme design and impact, covering six key elements:

- Summary of the programme: covers programme jurisdiction, organisation, start year and current programme status.
- General project details: describes programme premise, target customers, eligibility criteria and method of DR event notification.
- Incentives: outlines how participating customers are rewarded for participating.
- DR events: outlines event specifics like duration and frequency, and impacts like participation levels and aggregated load reduction where that information is available.
- Timeline and commitment period: covers what time of year the DR programme typically runs and enrolment period.
- Technologies and load control: presents the mode of load control and types of technologies utilised in the programme.

The detail in these case studies will assist with the creation in the next CoolDown project work package of a longlist of potential cooling DR programmes which could be trialled in the UK.

Case study #1: Smart AC

Summary	
• **Jurisdiction:** North and Central California • **Average programme impact (as at 2022):** 18.5MW • **Organisation:** Pacific Gas & Electric (PG&E)	• **Programme vs. pilot:** Programme • **Start year:** 2007 • **Status:** Ongoing
General project details	
• **Overview:** – A direct load control AC programme where customers receive a one-time incentive for allowing PG&E to cycle their AC during the summer in response to California Independent System Operator (CAISO) wholesale market, or during periods of system or local area emergencies for PG&E capacity. – Customers with a Smart AC thermostat or Smart AC switch can enrol.	
• **Target customer:** Residential electric customers	
• **Eligibility/Criteria:** – SmartAC thermostat customers must have at least one Wi-Fi enabled smart thermostat, have a Wi-Fi network that is always on, have central AC connected to an eligible smart thermostat, and not be enrolled in another PG&E or third-party energy incentive programme. – SmartAC switch customers must have central AC unit or heat pump in suitable operating condition, have single-stage central AC units that operate during PG&E summer peak periods (approximately 5pm-8pm), have the homeowner or property owner's written permission to participate in SmartAC, and not be a participant in other energy incentives.	
• **Notification method:** – Customers get emails and can receive event day notifications on their smartphones using the free "If This Then That" (IFTTT) app. An X (formerly Twitter) account is required to use the app.	
Incentives	
• Incentives are fixed. • SmartAC switch customers receive a fixed $50 when they enrol and receive free technician support for their AC system for as long as they participate. • Smart AC thermostat customers can enrol with a smart thermostat they already own and receive a fixed $75; or get $120 off a new smart thermostat. • Smart AC thermostat customers get a fixed $25 at summer end for enrolment in the programme.	
DR events	
Event duration: • Allow PG&E to cycle their AC for up to 6 hours a day and a maximum of 100 hours per summer season.	
Event participation: • 59,646 customers were enrolled in SmartAC for programme year (PY) 2022. • PY 2022 enrolled load = 187.3MW (3.14 kW/participant) • PY 2022 aggregate impact of programme = 18.5 MW (0.31 kW/participant).	
Event regularity: • There were 10 SmartAC events across 8 event days in PY 2021.	
Timeline and commitment period	
• Programme runs every summer from May 1 to October 31.	

• Customers can unenroll at any time by calling PG&E.
Technologies and load control
• Direct load control. • Upon enrolment in SmartAC, PG&E installs a smart thermostat or installs an AC control switch (Tantalus) on the participant's AC unit that communicates bi-directionally over the AMI network. • Legacy technology, installed prior to August 2017, is capable of one-way communication over commercial paging system and include programmable communicating thermostats (PCT) and switches. • When events are called, PG&E send signals to PCTs and switches, cycling AC units with switches for 50% of each half-hour using adaptive algorithms.

Case Study #2: Regulated Peak Pricing Pilot

Summary	
• **Jurisdiction:** London, Canada • **Programme impact:** 9.4 MW • **Organisation:** London Hydro	• **Programme vs. pilot:** Pilot • **Start Year:** 2017 • **Status:** Closed
General project details	
• **Overview:** – Critical peak pricing trial of cooling flex with and without real time data. Designed to test the impacts of two treatments (Real-Time Information [RT] & Critical Peak Pricing [CPP]) on three distinct participant groups (RT, CPP, RT & CPP)	
• **Target customer:** Mostly residential	
• **Eligibility/criteria:** – No requirements were explicitly stated other than being a London Hydro customer. – All CPP participants are provided with a smart plug and load control switch.	
• **Notification method:** – CPP participants received 15 minutes' notice for a CPP event through the Trickl app.	
Incentives	
• All participants received a fixed $100 incentive for participating ($25 at enrolment, $75 at end of pilot). • CPP: pricing during called peak events was $0.595/kWh – nearly 10x the discounted off-peak rate.	
DR events	
Event duration: • Events lasted 1 hour between 5 - 8pm.	
Event participation: • Of 159,040 London Hydro customers, 1,800 were enrolled in this pilot. • Typical peak load: 719 MW. • Participant average monthly non-coincident summer peak demand: ~ 5.25kW. • This corresponds to 9.4 MW enrolled across all pilot participants.	
Event regularity: • 36 events (18 summer, 18 winter)	
Timeline and commitment period	
• Enrolment Period: July 2017 – May 1, 2018 • Pilot Period: May 1, 2018 - April 30, 2019	
Technologies and load control	
• Customer-controlled load. • Rainforest's EAGLE-200 Energy Gateway provided real-time data from the home meter. • Trickl: a mobile app developed by London Hydro that presented real-time consumption data to users. Allowed users to activate the switches from their phones and commence Automated DR	

Case Study #3: Energy Wise Business

Summary	
• **Jurisdiction:** South and North Carolina, USA • **Average programme impact (as at 2021):** 10.14MW • **Organisation:** Duke Energy	• **Programme vs. Pilot:** Programme • **Start Year:** N/A • **Status:** Ongoing
General project details	
• **Overview:** – Duke Energy reduces customer's AC operations by sending a signal to cycle off and on the customer's AC unit or electric HP compressors. – Customers can select from 3 offerings based on the percentage reduction of the normal on/off frequency of the cooling technology. Offerings include a 30% cycling level (CL), 50% CL and 75% CL	
• **Target customer:** Non-residential customers	
• **Eligibility/Criteria:** – Must be a non-residential Duke Energy electric customer. – Must consume an average of at least 1000kWh per month. – Must have one or more central air conditioning or heat pumps. – Must have readily available, password-protected Wi-Fi for the thermostat option.	
• **Notification method:** – Customers receive an advance notice of a scheduled DR event as far in advance as possible, no later than 4 hours before the event commences.	
Incentives	
• Incentives vary by customer offerings – for 30% CL, 50% CL and 75% CL, customers receive annual credits of $50, $85, and $135 per load control device, after the first year. • Customers also have extra energy bill savings from running energy on the thermostat's schedule.	
DR events	
Event duration: • Events may occur for up to 4 hours each day during the programme months; occurred between 4 and 7pm in 2021	
Event participation: • 8927 customers enrolled in the summer event as of end of PY 2021	
Event regularity: • Minimum of one event per season • Five summer events in 2020/2021 DR programme	
Timeline and commitment period	
• The summer programme runs from May 1 – September 30	
Technologies and load control	
• Direct load control. • Participating devices may be controlled by Duke Energy Progress (DEP) or Duke Energy Carolinas (DEC). • Duke Energy installs new Wi-Fi programmable thermostats or cellular switch within the business premises. Customers who opt for thermostat have access to the Energy Wise Business portal using a smart device; the portal allows customer to monitor and modify temperature set points, and customise cooling and heating schedules, etc.,	

Case Study #4: Interruptible Service

Summary	
• **Jurisdiction:** Arizona, USA • **Average programme impact:** N/A • **Organisation:** Tucson Electric Power (TEP)	• **Programme vs. Pilot:** Programme • **Start Year:** 2023 • **Status:** Ongoing
General project details	
• **Overview:** – Participating commercial customers receive a bill credit by agreeing to service interruptions that help TEP manage its energy resources efficiently, especially during times of high demand.	
• **Target customer:** Commercial and industrial customers	
• **Eligibility/Criteria:** – Available to customers receiving electric service over 3,000 kW and are willing to subscribe to at least 1,000 kW of interruptible load. – This programme is not available for resale and cannot be run in conjunction with other interruptible rate schedules.	
• **Notification method:** – The customer must indicate service points that may be available for interruption with a 30-minute notice.	
Incentives	
• Customers who elect service under this programme receive a monthly interruptible credit for each of the five summer months in which an interruption may occur. • Bill credit will be calculated by taking the Market Value Capacity Price applicable for the interruptible load season multiplied by the customer's nominated interruptible load.	
DR events	
Event duration: • Maximum of 6 hours for each interruption event.	
Event participation: • N/A	
Event regularity: • No more than two interruptions in a day during the five summer months in the interruptible load season.	
Timeline and commitment period	
• Interruptions occur during the interruptible load season which is from May through September. • To participate in this programme, companies must subscribe between March 15–April 15 of each programme year.	
Technologies and load control	
• Participating customers are responsible for the installation and maintenance of communication, relay and breaker equipment needed to qualify for service and all related expenses.	

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