Mapping Energy in the Square Mile: Citizen's Science Handbook

Bruno Bingley, Research Assistant in History and Editor of the Handbook
Nazila Salimi, Research Assistant in Heat
Dr Yangang Xing, Science Lead
At Nottingham Trent University

Carole Patey, and Laurie Dighton at Square Mile Churches Project

Jonathan Ward Net Zero Carbon Buildings Lead, LDF

With Square Mile Churches Engineering Volunteers and Participated Schools

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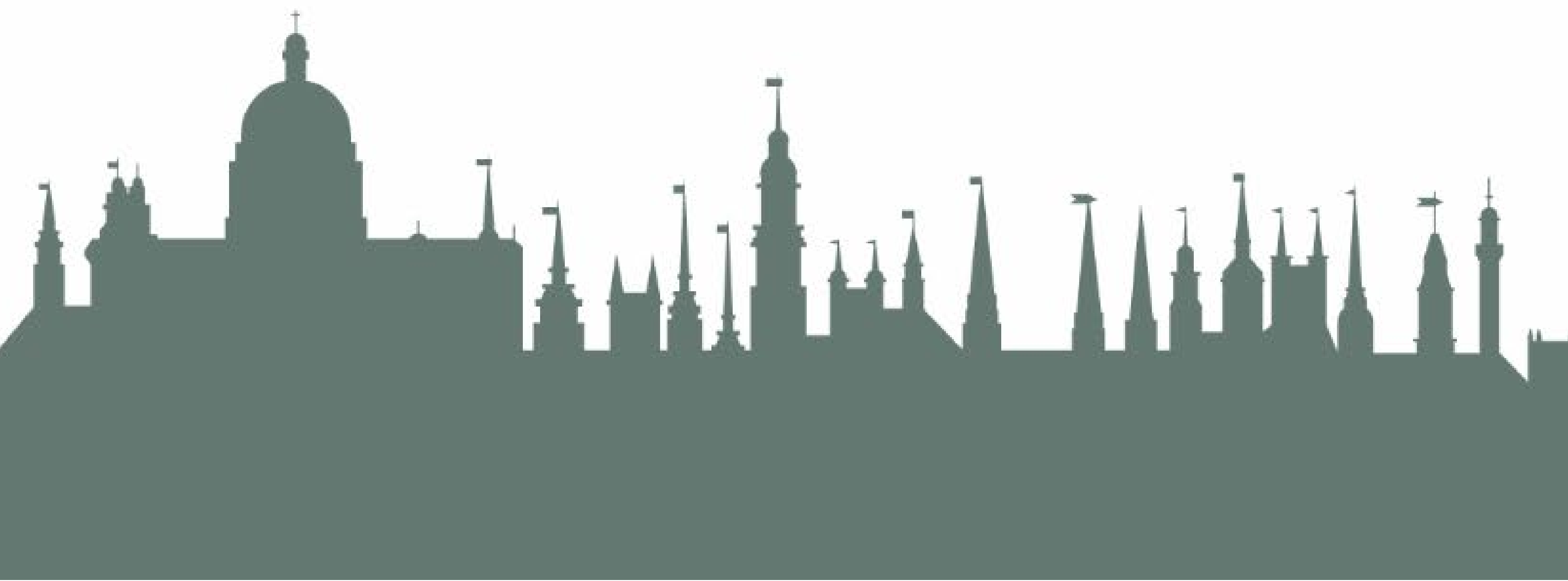

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Foreword

With the global energy market making a decisive move towards net zero carbon in the 2020s, England's energy transition has become the subject of general debate. According to the International Agency, the transition to Net Zero carbon will result in the loss of 13 million jobs in the fossil fuels sector and the creation of 30 million jobs required to support the transition.

London's square mile encompasses the historic city of London.. It is home to a wealth of historic architecture and heritage buildings including St Bartholomew's Hospital, St Paul's Cathedral and 38 historic churches designed by the likes of Sir Christopher Wren, Nicholas Hawksmoor and George Dance the Younger. Protecting these architectural marvels whilst making them more sustainable is key to a greener future in London.

In this short handbook you will learn about London's past energy transitions. You will also learn about new technologies which are helping make the present transition possible.

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SECTION 1: Energy Transitions in the Square Mile

The Political Coal Heavers, *The Oxford magazine, or Universal Museum*. 1769.

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1. Trees for Fire

In 47-50 AD the invading Romans had begun to establish their own city on the Thames. This city was named Londinium and was located on the site of the City of London as we know it today. The Roman walls of Londinium are still visible in the city to this day. In the city, they burned wood and charcoal for cooking and heating.

Map of Londinium. Artwork by *RomanLondon.co.uk*

2. Carmen

Around 1066, long after the Romans had abandoned Brittanica and been taken over by the Normans, London was reestablishing itself as England's major city. New trades were established to move fuel from one place to another.

The workers were known as fuel sellers and carmen; they drove horse and carts around London selling:

- Wine
- Goods
- Wood
- Charcoal

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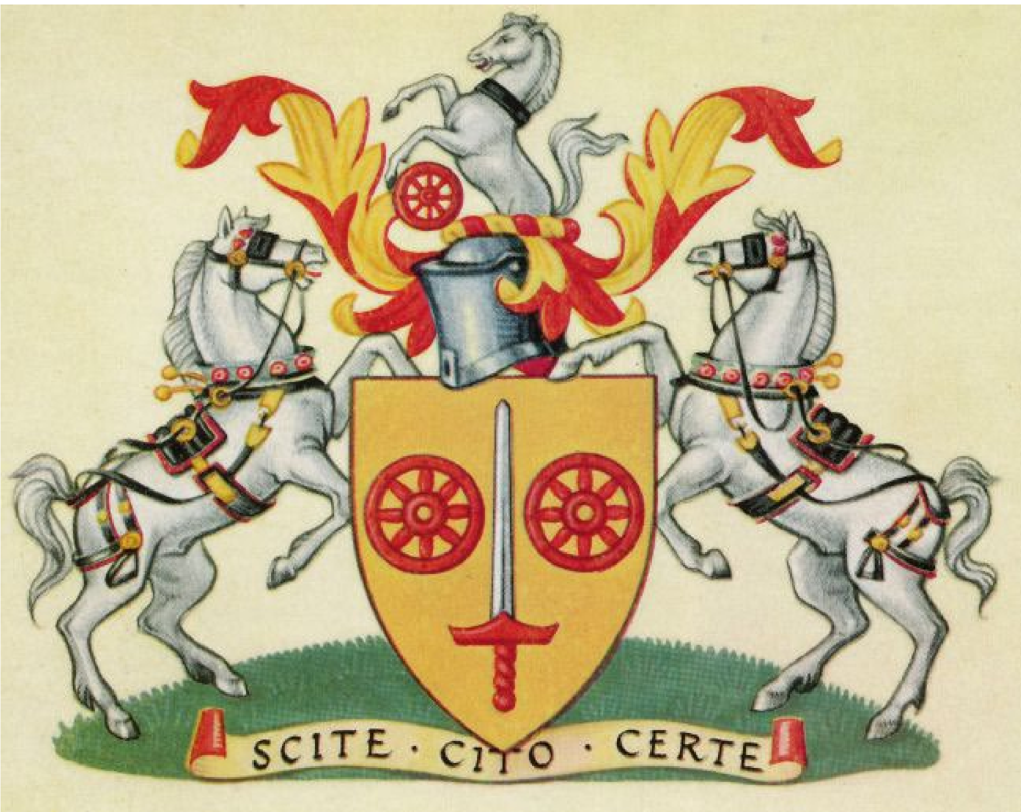
3. The Worshipful Company

In order to stop the King from forcing the carmen to transport royal goods for low wages, they established a Livery Company. Livery Companies were professional associations or trade guilds that regulated specific trades and protected the interests of their members. These organisations played an important role in maintaining standards, setting fair prices, and supporting their tradespeople. The Worshipful Company of Carmen, which regulated the carting and transport of goods, was established in 1517 to organise and oversee the selling of fuel throughout the city and to defend the rights of Carmen.

Brothers in Arms

Each livery company had a badge or emblem, known as a coat of arms. This gave them their identity and represented their group's values.



Above is the coat of arms of the Carmen Livery Company. It shows a shield with two cartwheels and a sword, three horses and a frog-mouth helmet used for jousting. The Latin inscription at the bottom reads:

SKILFULLY, SWIFTLY, SURELY

As we can see, the coat of arms of a livery company is effectively a visualisation of a company motto. This specific heraldry was designed in 1938 and is still used by the company today.

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4. Coal is the Goal

Coal had been mined in England since the 13th century. Initially only the poor would burn coal, the wealthier inhabitants of the city favoured wood as fuel due to the unpleasant black smoke produced by coal when burned. However, when England's forests were depleted through the excessive us of wood to burn as fuel, coal became popular across all social classes.

Coalmining in Britain

Coal in medieval times was known as ***Sea Cole*** because in Northumberland coal often washed up on the shore. It had to be transported into London by boat, via the River Thames. It was mainly mined in the North of England, the Midlands and Wales.

Made to Measure

During medieval and early modern times, coal was measured by volume instead of weight. ***Chaldrons*** were a volume measurement of coal or wood which roughly translates to cauldron. In the early stages of the coal trade, there was a general understanding of the right amount of coal and also what a fair price might look like. A chaldron of coal being a dry volume measurement changed over time. There were two types of chaldron:

	1421	**1678**	**1694**
London *Chaldron*	1,420 kg	1,420 kg	1,420 kg
Newcastle *Chaldron*	907 kg	2,670 kg	2,690 kg

Heavy Cargo

The table above shows the weight of the ***London Chaldron*** and the ***Newcastle Chaldron*** as estimated by Historian John Nev. In 1678 the Newcastle Chaldron was fixed by law at 2,670 kg but coal merchants had increased the measurement to 2690 kg by 1694. The chaldron was legally the most coal that could be transported by road. Any more weight could potentially damage the highways.

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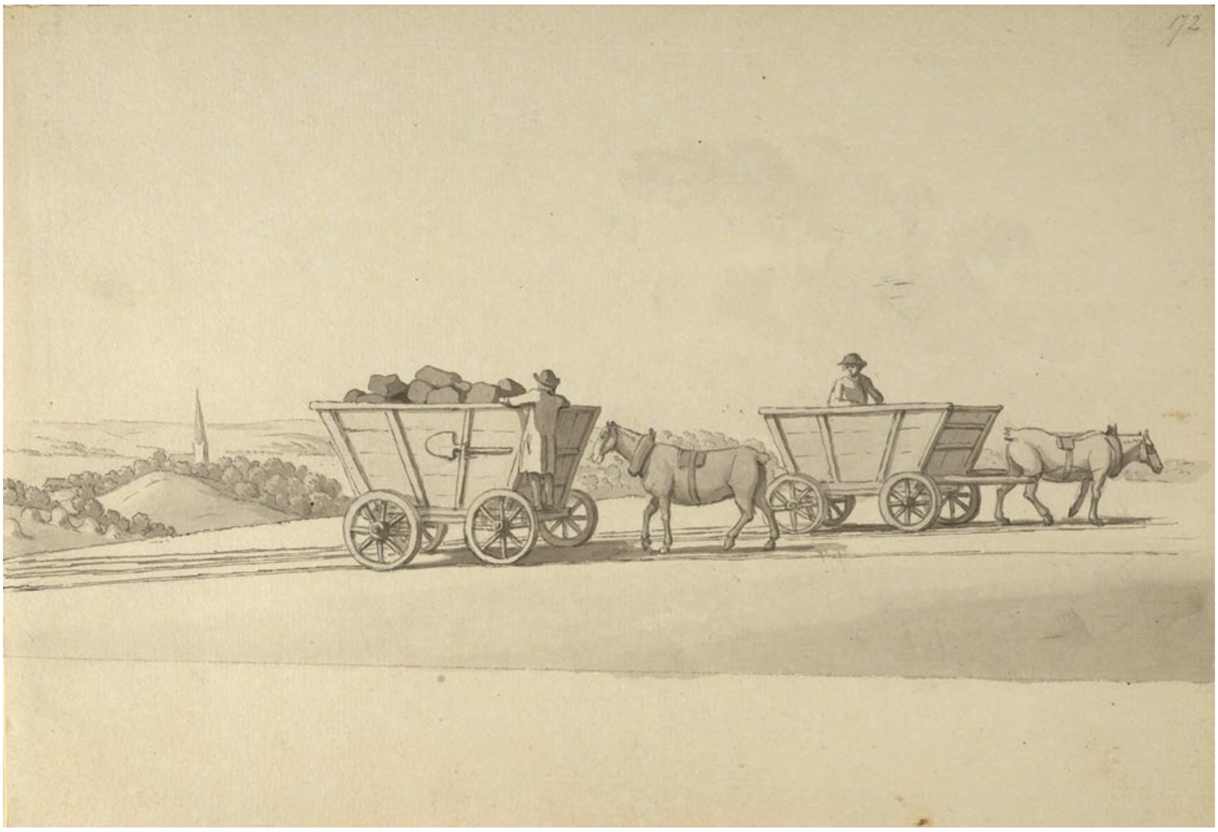

Chaldron Wagons, opposite Ryton, Northumberland.

5. More Power, More Work

A major transition in London's fuel history was the move from wood to coal as the most popular fuel source. In 1550 London's entire coal consumption was fulfilled by 22 fuel carrying ships known as ***colliers***. 65 years later, in 1615, coal requirements had increased to two hundred ships. New occupations were established to help with the increased demands of coal transportation.

For a Gallon of Rum

One of the most important new trades established in London during this time was ***coal heaving***. Coal heavers unloaded heavy loads of coal from the hull of a collier onto smaller boats or directly onto the docks of the Thames.

Coal heaver gangs were made up of 16 men and a ***foreman*** who arranged the gang and got them work. They met at local pubs and when coal ships came in worked in 4 hour shifts to unload the coal. They were paid with a gallon of rum.

Whippers and Pulleys

In 1786 baskets and ***whippers*** were introduced. Whippers began to pull baskets of coal up through the holds using pulleys and ropes, reducing the size of the gangs by half, now requiring only eight men.

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The Coal Trade in London

The following table demonstrates the complexity and size of the pre-industrial coal trade in London There were many professions established solely for the purpose of moving and selling coal.

Colliers	Captains of the coal-carrying ships, the colliers which transported coal from the North up the Thames to London.
Coal-mongers	Coal merchants on horse drawn carts who would travel around London.
Wood-mongers	Wood merchants on horse drawn carts who would travel around London.
Coal-heavers	Gangs of off-duty brigadiers hired to haul coal from the hull of a collier to the deck and up onto the docks. They used shovels.
Foremen	The leader of a coal-heaver gang. Tasked with finding the gang work and paying them in rum.
Whippers	In 1786 basket and pulley systems were installed on ships, the whippers were employed to pull heavy baskets of coal up from the hull and onto the deck.
Lightermen	Men on small rowing boats employed to transport coal and other goods to the docks.
Carmen	Merchants carrying all sorts of goods including wine, cheese, coal and wood.
Coal Weighers	Individuals called upon to weigh coal measurements and ensure fair prices.

Off t' pit wi' ya

The coal coming through London had to be mined and unfortunately, this dangerous occupation employed children as young as four years old. The typical starting age for children entering coal mines as employees was between eight and nine years old. We know this thanks to the ***Children's Employment Commission*** which in 1842 carried out extensive investigations into child labour in England and Wales.

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6. Turn Pike and Run

In the 1750s new transport routes were built across England known as ***turnpikes***, which were the precursors to England's motorways and waterways. They were roads maintained by the government with money paid by travellers at the toll gates. These measures helped to protect fuel-sellers from highwaymen and robbers.

Highwayman holds up a coach, by illustrator E. A. Holloway. 1922.

The turnpike movement of the 1750s helped to mobilise trade inland by offering safe and direct travel routes across the country to merchants and fuel sellers in the forms of canals and highways.

7. Lost Arts

In 1770 the trade was centred around the ***London Coal Exchange***. However, the coal trade had begun to spiral out of control, a lack of proper regulation and increased demand caused chaos as more people attempted to enter the trade. Government intervention was necessary, and a parliamentary inquiry began to change the rules of coal selling. Many of the professions and Livery Companies established in the medieval period became obsolete during the transition to the industrial fuel trade.

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New Rules

In 1827 the ***Coal Meters' Society*** was established which essentially operated as a coalition between coal factors (fuel traders) and merchants (importers) and had a different president every month. The newly reestablished trade was so effective that the Woodmongers and Coalmongers' trades were essentially abandoned overnight.

Member of the Royal Society Hylton B. Dale wrote:

> *When the enquiry into the City Companies was held 1826-1828, a summons was sent to the Woodmongers, but no one appeared.*

8. Smokehouse

Burning coal had its consequences. During the Industrial Revolution, England's major cities were wreathed in black smoke produced from the huge quantities of coal being burned. Buildings were covered in soot and respiratory diseases were very common amongst the people of London.

Air pollution had been an issue in London since the 1200s, however, the massive rise in coal power made the issue even worse. The first move against pollution in England was made by King James I who attempted to pass legislation to restrict coal burning, but it ultimately proved ineffective. Following this, with coal burning on the rise, coal dust and water vapour began to combine in London to produce thick dark ***smog*** (smoke and fog) which impaired visibility.

The Great Smog

In 1952 London experienced its most significant bout of smog, known as ***the great smog***. On December 5th, the smog was so thick, accounts recalled that individuals could not even see their own feet. The event was caused by an anticyclone trapping cold air underneath hot air, meaning that of all the pollution from factories was trapped at ground level. It lasted for five days and caused an estimated 12,000 deaths.

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A London Bus navigates the Great Smog of 1952.

Cleaner Air

In response to the great smog, in 1956, the government passed the ***Clean Air Act***. The Act stopped coal-burning in the city at both domestic and industrial levels. Smoke free zones were marked across the city and buildings were thoroughly cleaned of soot and coal dust which accumulated on their surfaces giving them a murky appearance. St Paul's Cathedral required extensive cleaning as it was almost blackened by the pollution in the air.

No Smoke Without Fire

It was in the same century that Thomas Parker invented ***Coalite*** a smokeless form of coal which helped to reduce air pollution in London and beyond. The process for creating Coalite involved carbonising regular coal at 640°C. The new fuel was so effective that the in 1936 the Smoke Abatement Society awarded Parker a posthumous gold medal.

9. The Big Switch

By 1835, almost all of London was heated by approximately 3.5 million tonnes of coal, requiring over 12,000 shiploads, transported by a fleet of 3,000 colliers. The mass adoption of coal prompted engineers to begin experimenting with the fuel and start to develop technology which by the 1800s would become the steam engine. The invention of the steam engine revolutionised how coal was transported across the country and to London. The industrial revolution saw coal production increase enormously and continuously throughout the Victorian period and up to 1916, beginning to level out as electricity became more popular.

Electrifying Stuff

The first electric power station was established at Holborn in 1882. Following World War II, government action brought all electricity generating power stations under one roof. The board was known as the British Electricity Authority in 1947; it changed to the Central Electric Authority in the 1950s and changed again to the Central Electricity Generating Board in 1957. Many of London's local power stations began to close when new, larger power plants were built outside the city. In 1989 the UK's energy industry was again denationalized, allowing private companies to take over the existing power stations and provide energy to London and Britain at large. With the increasing concerns about climate change in recent decades, London is now undergoing a new transition characterized by green spaces, solar panels, tidal power and green tariffs.

Green Energy

In ***Section 2*** we will discuss the viability of an innovative sustainable technology for London, which recycles waste heat and supplies it to homes and buildings throughout the square mile.

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SECTION 2: Energy Transition and Urban Waste Heat Recovery

Bunhill Energy Centre.

1. Introduction

This section introduces the ongoing energy transition and the potential of reusing waste heat. It will breakdown the problems faced by engineers in reaching waste heat, transporting it to the surface, and then distributing it to houses and buildings such as the City of London Churches.

Waste Not Want Not

London is currently attempting to decarbonise heat and power generation while improving its energy efficiency and resilience, particularly in dense urban settings such as city squares and transport hubs. These environments are not only major energy consumers but also harbour significant untapped thermal resources, including waste heat from buildings, underground infrastructure, and transport systems. Despite its potential, urban waste heat remains an underutilised component of the energy transition.

2. The Potential of Waste Heat

The subterranean environment beneath historic churches in central London is complex and congested by London Underground lines, utility corridors, and other subsurface infrastructure. London's urban environment generates significant amounts of waste heat from buildings, underground transport systems, data centres, and industrial processes. Much of this residual heat is currently vented into the atmosphere, yet it represents a largely untapped resource for sustainable energy.

Pole Position

With its dense infrastructure and high heat demand, London is uniquely positioned to harness this energy through technologies such as heat pumps, heat exchangers, and district heating networks. Recovering urban waste heat not only improves energy efficiency but also supports the city's decarbonisation goals and resilience in the face of climate change.

Close Proximity

Proximity to underground tunnels and ventilation shafts can enable the extraction of waste heat from the London Underground system, supporting ambient loop or low-temperature district heating networks. Understanding the depth and distribution of underground infrastructure is essential for evaluating the feasibility of low-carbon heating strategies.

3. London In Depth

In 2018, senior graphic designer at Arup and Silver Salt, Daniel Silva was on the tube and wandered "How far down am I?". This question was the start of an immense journey, which took Daniel around London, as he researched and modelled a series of images and diagrams which demonstrated the various depths of the London

Underground Rail system. He created thirty-three images in total under the project name ***Down Underground***. His work helped pave the way for waste heat recovery investigation by giving researchers an accurate picture of depth in the London Underground.

London Depth Analysis

The following graph illustrates the variation in station depths across the Tube network, from shallow stations to deep-level stations such as Hampstead, located more than 58 metres below ground. This comparison highlights the need for detailed geospatial analysis in assessing renewable heating options for historic sites.

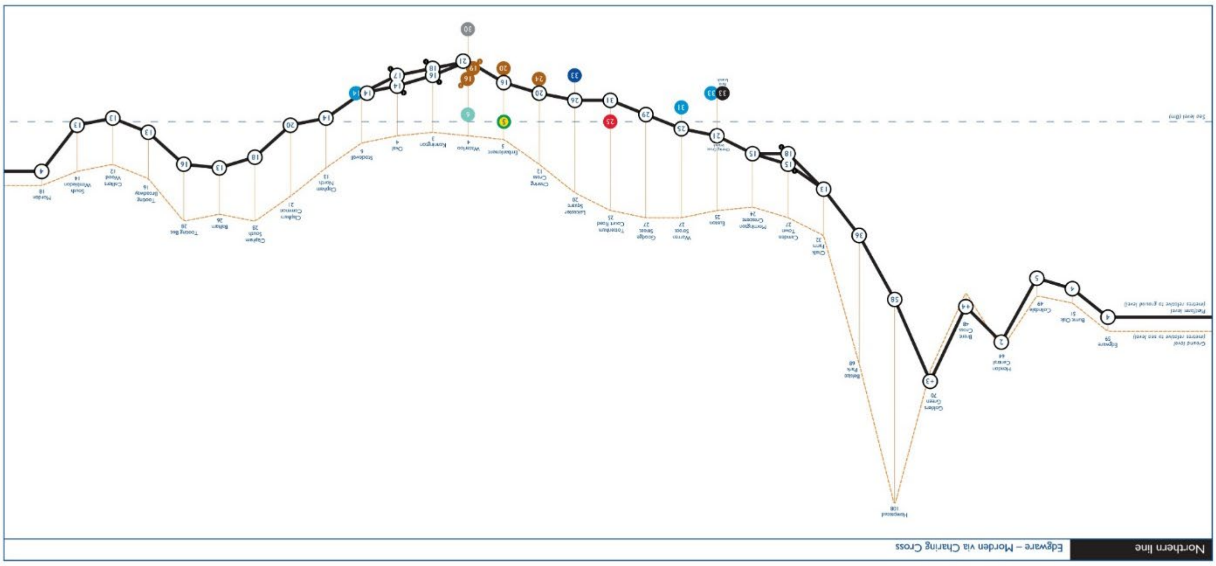
Understanding Silva's Diagram:

Levels – The orange line on each diagram represents ground level, and the blue line is sea level (which conveniently never changes), while the coloured line shows the position of the platform of each station below ground level, in metres.

Numbers – The number next to the name of each station shows the ground level at that station relative to sea level.

Colours – The coloured dots represent platforms on other tube lines at the same station, which really puts the difference between sub-surface and deep-level tube lines into perspective.

Example – The ground level entrance to Earl's Court station is 8m above sea level, and the station platform is 6m below ground level (Londonist, 2018).



Daniel Silva, Northern Line Depth Diagram, 2018.

4. Mapping Energy Heat Differentials

In order to establish the potential heat differences between the churches of this project and their closest tube stations, spot measurements were carried out by A-Level students on the 22nd of January 2025, between 11:00 am and 1:00 pm. They measured the temperature at three locations: inside the church, outside the church, and inside the nearby tube station. The following diagram illustrates the temperature differences observed between different churches and tube stations. Here are the results

Church	Average Indoor Temperature	Tube Station	Tube Station Temperature	Temperature Difference Indoor vs Tube	Temperature Difference Outdoor vs Tube
All Hallows London Wall	14.71	**Liverpool Street**	21.07	-6.36	11.07
Christ Church Spitalfields	19.10	**Liverpool Street**	21.07	-1.97	11.07
Holy Sepulchre	16.60	**Chancery Lane**	21.30	-4.70	11.30
St Andrew by the Wardrobe	18.43	**Blackfriars**	11.57	6.87	1.57
St Giles Cripplegate	15.28	**Moorgate**	22.14	-6.86	12.14
St Katherine Cree	17.75	**Aldgate**	[redacted]		
St Lawrence Jewry	18.28	**St Pauls**	19.30	-1.02	9.30
St Margaret Pattens	16.57	**Monument**	[redacted]		
St Mary Abchurch	20.17	**Canon Street**	13.27	6.90	3.27
St Mary Aldermary	19.33	**Mansion House**	17.50	1.83	7.50
St Mary Woolnoth	16.43	**Bank Station**	23.03	-6.60	13.03

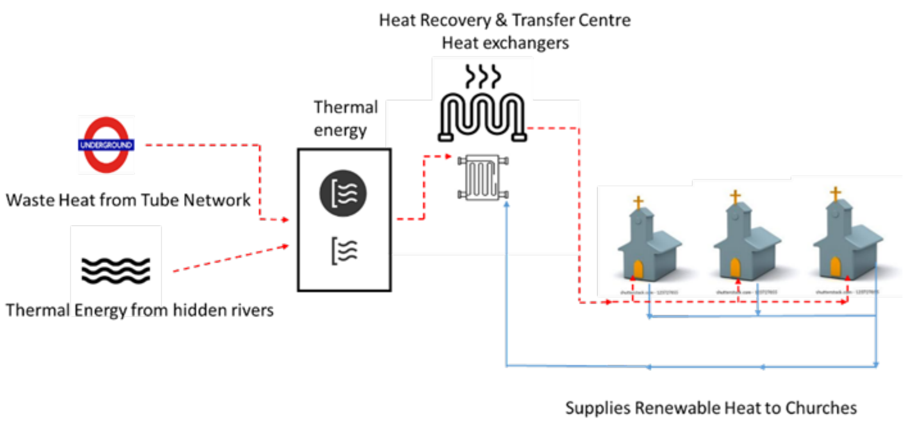
Heat Measurement Day (photos by: Andy Sillett)

5. Heat Pumps and District Heating Systems

Heat pumps are energy-efficient systems that transfer heat from one place to another, typically from a low-temperature source to a higher-temperature space. They can extract heat from the air, ground, or water and upgrade it for use in space heating, hot water, or cooling. Unlike conventional boilers, heat pumps require only a small amount of electricity to move heat rather than generate it, making them a key technology in low-carbon heating solutions.

District Heating Systems

Designing a district heating system based on waste heat recovery from the London Underground and Hidden Rivers provides an innovative, sustainable solution for the City of London's historic churches. This approach can lead to substantial energy savings, reduced carbon emissions, and contribute to net-zero goals. By considering scalable, cost-effective implementation and working closely with stakeholders, such a system could set a precedent for other cities with heritage buildings looking to modernise their energy systems.



Conceptual District Heating System for Historic Churches Using Waste Heat from the London Underground and Hidden Rivers

District Heating Networks

District Heating Networks (DHNs) have undergone significant evolution over the past few decades. While early systems were based on high-temperature steam or hot water distribution, modern generations are designed for efficiency, decentralisation, and integration with low-carbon energy sources.

- **4th Generation DHN**s operate at low supply temperatures (40–60°C). These systems are designed to:

    - Integrate with renewable energy sources such as solar thermal, geothermal, or large-scale heat pumps.
    - Minimise distribution losses.
    - Enable reversible heat exchange, where buildings can both consume and return heat.
- **5th Generation DHN**s represent the next phase of innovation. These are ambient temperature networks, typically operating around 10–25°C, and rely on localised heat pumps within each connected building to upgrade the temperature to the level required for space heating or hot water.
    - These systems are highly efficient, as they avoid large-scale thermal losses and enable energy sharing between buildings (e.g., recovering waste heat from cooling systems).
    - Their decentralised nature supports flexibility, smart control, and modular expansion.

Both systems offer excellent opportunities for low-carbon retrofitting of historic and mixed-use urban environments.

Despite the advantages of modern DHNs, several practical barriers exist, especially in heritage-rich, densely built areas like central London:

- **Underground Congestion**: The subsoil is already filled with utilities, tunnels, and foundations. Installing new insulated pipework or energy loop systems requires complex coordination with local authorities, utility companies, and transport agencies.
- **Planning Constraints**: Conservation areas often restrict intrusive infrastructure works that could affect historic pavements or surrounding structures.
- **Coordination Required**: Success hinges on alignment with borough energy strategies, such as those in the London Environment Strategy or local development plans. This involves long-term coordination between public, private, and third-sector actors.

6. Discussion and conclusion

This section has explored the evolution of London's energy transition from the 12th century to the present, highlighting how energy technologies have adapted in response to shifting social, environmental, and infrastructural needs. It has also examined the potential to harness local sources of waste heat, particularly from the London Underground and subsurface water bodies, to support low-carbon heating solutions for historic churches. The Underground maintains a relatively stable internal climate due to train operations and mechanical systems, with a large portion of waste heat currently expelled through ventilation shafts. By capturing this warm air with fans and heat exchangers and upgrading it using water-to-water heat pumps, it can be redirected to nearby buildings, including churches located close to these outlets. Beneath parts of central London, the culverted Rivers Fleet and Walbrook also offer opportunity for water source heat pumps (WSHPs), maintaining consistent year-round temperatures of 10–12°C, provided flow rates and access conditions are suitable.

In parallel, localised, occupant-focused heating strategies—such as radiant panels, under-pew heaters, and heated seat cushions—offer efficient solutions for intermittently used heritage spaces. When combined with fabric improvements and, where possible, integrated into district or waste heat networks, these approaches present a practical, conservation-sensitive route towards zero-carbon heating in historic buildings.

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Images

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Map of Londinium. Artwork by *RomanLondon.co.uk* (Public Domain)

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Conceptual District Heating System for Historic Churches Using Waste Heat from the London Underground and Hidden Rivers

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