Transport for London

Prior Information Notice

Opportunities to utilise heat from London Underground ventilation shafts

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1 Introduction

At 37%[1], heating accounts for the largest proportion of UK Greenhouse Gas emissions. About 90% of UK homes currently use gas boilers[2]. Gas combustion also accounts for 38%[3] of NOx emissions in central London. Meanwhile, there is enough waste heat in Europe to heat all of Europe's building stock[4]. Waste heat can be used in conjunction with heat pumps to produce very low or zero carbon heat and cooling to buildings. Very little waste heat is currently captured and channelled into the urban environment, but its use may be important to achieve decarbonisation.

This Prior Information Notice (PIN) is issued by Transport for London (TfL) and seeks to inform the market of potential future opportunities to utilise waste heat from ventilation shafts which extract air from the London Underground deep tube network[5]. TfL expect to publish a Market Sounding Questionnaire later in the year to invite feedback from the market to better understand the appetite for potential schemes among potential off-takers, as well as perceived risks and opportunities.

Currently, TfL are looking for parties that may be interested in such an exercise to identify themselves and express their interest via TfL's e-tendering portal. Please note that in order to do so (and in order to access future market sounding or tender exercises published by TfL), organisations will need to register as a supplier via the following link:

https://procontract.due-north.com/Register

To support TfL's work on waste heat, technical feasibility has been completed by specialist consultants to understand the scale of the opportunity and develop a shortlist of potential sites. This work builds on the implementation of the ground-breaking City Road / Bunhill II project in Islington which became operational in March 2020. Bunhill II utilises waste heat from the Northern Line, allowing 550 homes and a primary school to be served by expansion of an existing heat network.

When the Market Sounding Questionnaire is launched later this year, TfL is particularly interested in receiving responses from building owners (public and private), developers, heat network operators, specialist supply chain, academics and specialist consultants. We are interested in identifying schemes that might be ready to proceed, schemes in early development stages and also the market view of any barriers that may be preventing otherwise worthwhile schemes progressing.

Please note that TfL does not have any confirmed or immediate plans for waste heat schemes at any of the sites outlined in the report. The purpose of the Market Sounding Questionnaire will be to help inform TfL of the existing and likely future market appetite for such projects. **At this stage, TfL is unable to respond to questions or requests for clarification**; such requests will be facilitated upon release of the Market Sounding Questionnaire. Any organisations that express an interest via the portal at this stage will be notified once the Market Sounding Questionnaire becomes available.

1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766109/decarbonising-heating.pdf
2 https://energysavingtrust.org.uk/blog/decarbonisation-heat-%E2%80%93-crossroads
3 https://policyexchange.org.uk/why-london-needs-a-boiler-scrappage-scheme/
4 https://www.reuseheat.eu/project-brief/
5 The deep tube network comprises: Jubilee, Northern, Piccadilly, Central, Bakerloo, Victoria, Waterloo and City lines. Other lines have limited potential for heat capture as they are naturally better ventilated, due to larger tunnels and proximity to the surface – they do not have large ventilation shafts of the type assessed in this study.

2 Background Information

3.1 Objectives

The London Environment Strategy has a key objective for London to be zero-carbon by 2050. The Greater London Authority (GLA) compiled a report in 2013; the Secondary Heat Study – London's Zero Carbon Energy Resource. This report examines the availability, cost and energy utilisation considerations of secondary heat sources in London and issues associated with their integration with heat networks and with the London building stock.

To help London to achieve the 2050 zero-carbon goal, TfL is exploring the opportunities to utilise waste heat from ventilation shafts on the London Underground deep tube network. The heat from the deep tube tunnels, dissipated primarily by the trains, offers a year-round source of low-grade heat suitable for utilisation in district heating networks for building heating and other low carbon energy initiatives. Air expelled from TfL's ventilation shafts is typically in the range of [18-28˚C] depending on location and time of year.

3.2 Overview of work to date

On TfL's behalf, Ove Arup & Partners Ltd has carried out work to understand the viability of the potential opportunities across each of the deep tube lines. The scope for this work was to assess;

- the nature and quality of the resource available at the relevant ventilation shaft locations; and
- the Economic and Social business case for utilising this heat within the adjoining built environment.

This work was carried out in three stages (see Appendices 3, 4 & 5):

Stage 1: Sift 1. This first sift started with 55 identified sites and was designed to identify those ventilation sites that appeared both feasible and viable to take to feasibility design stage. It focused on four key criteria: Access, Space, Waste Heat Receptors/Consumers and District Heating Network Route. This reduced the list of sites to those considered most practicable and viable for delivering a heat recovery scheme.

Stage 2: Sift 2. This stage took the most promising sites and undertook a high-level feasibility assessment focused on the following criteria using whole-life appraisal methodology: Operational, Construction, Maintenance, Costs, Social and Economic benefits and Risks. Following this work, the list of priority sites was reduced to six, with some further sites ranked and identified as potential future options to be further assessed.

Stage 3: Feasibility. The six potentially most viable and deliverable sites were taken to full multidisciplinary feasibility design, with the designs taking into account the potential carbon savings, Capital/Operational costs and economic benefits to inform any potential investment decisions. Construction and delivery appraisals were also carried out, alongside engagement with key stakeholders to understand how best to move opportunities forward. The draft results of the assessments for the 6 sites are set out in *Appendix 5 – Phase 3 feasibility findings*.

Although the approach has been a sifting exercise to work out the most viable and deliverable sites we have not ruled out projects at any of the 55 sites. Our sifting criteria were based on a number of assumptions based on the current environment, some of which may be subject to change.

3.3 Reference Technical Design

The work undertaken by Ove, Arup & Partners Ltd assumes the concept technical design set out in *Appendix 1 – Basis of design*. The underlying principles of the reference design are the same as adopted for the recently commissioned City Road / Bunhill II scheme.

The more detailed, site specific concept designs undertaken for Phase 3 assessed sites have been developed to provide a technical solution that is operationally acceptable to TfL. TfL is willing to consider alternative design solutions that may also be operationally acceptable. Detail as to what constitutes operational acceptability is set out in *Appendix 2 – Operational constraints and design considerations*. This is a draft document that may be amended over time.

3.4 Commercial and Legal Structure

TfL has carried out an initial review of the commercial feasibility of engaging with the market to provide waste heat to projects. We have identified the following draft principles that schemes would need to consider:

- TfL does not currently have a budget to develop and deliver waste heat schemes. Therefore, projects will need to be revenue neutral for TfL and will need to cover their own capital and revenue costs. However, TfL is willing to work with interested parties to identify potential funding sources to develop and deliver projects.
- TfL holds data setting out the operational profile, temperatures and airflow rates for its ventilation assets and is willing to provide this data to projects to enable project sponsors to assess whether the potential waste heat resource is suitable for its needs.
- TfL has identified a technical solution that should be capable of being installed, operated and maintained with minimal interaction with TfL and its assets. Projects should presume that they will carry all design, installation, operations and maintenance risk.
- Projects should presume that they will arrange and pay for all necessary utility connections and inputs.
- Projects will be responsible for obtaining all necessary permissions and permits and ensuring regulatory compliance of the project on an ongoing basis.

3.5 Viability

It should be noted that TfL expects that through further investigation some sites currently considered viable will become less so. Likewise, sites not shortlisted through the initial study may prove to be more promising than expected. TfL remains open minded as to which sites might be taken forward into further project development if they are likely to be viable.

TfL is also aware that, in addition to the ventilation shafts considered as part of this study, there may be other opportunities to extract heat from the London Underground network. TfL is open to receiving responses in respect of such opportunities where the respondent can demonstrate that the opportunity may be unlocked with zero impact to TfL's operations.

3.6 Additional Documentation

The following Appendices are included with this Questionnaire:

- Appendix 1 – Basis of design;
- Appendix 2 – Operational constraints and design considerations;
- Appendix 3 – Phase 1&2 assessment scores;
- Appendix 4 – Ventilation shaft locations; and
- Appendix 5 – Phase 3 feasibility findings.

Appendix 1: Basis of design

Current TfL ventilation systems are based around the following key components:

- **Tunnels and ventilation shaft:** ventilation shafts provide a dedicated route to atmosphere for air to be either supplied/extracted to/from LU running tunnels and public areas.
- **Fan and headhouse building:** the headhouse building typically contains one (or more) ventilation fans located at ground level which supply/extract air to/from the railway environment. The headhouse also contains ancillary ventilation equipment such as transition pieces, sound attenuators, dampers and a ventilation control panel which ensure the system operates as specified by the design and in accordance with the local ventilation requirements for the operational railway.

The heat recovery system design is based around the concept of installing coils (air-to-water heat exchangers) in the airflow path, enabling transfer of heat from the warm air (typically 20-30°C) into the cooler 'primary water circuit' (5-20 °C).

The primary water circuit feeds a heat pump, which uses electricity to drive a refrigeration cycle (the heat pump) that transfers the 'low grade' heat in the primary water circuit to 'high grade' heat in the 'secondary water circuit'.

The secondary water circuit typically operates at temperatures above 50°C; however, this varies and is defined by the requirements of the heat receptor building. Lower temperatures give higher heat pump Coefficient of Performance (COP) and are preferable as the system will be cheaper to operate.

The heat pump shall be located in an energy centre located at the ventilation shaft site or at the point of connection to the customer. It is TfL preference that all the assets associated with the heat recovery system, excluding the heat recovery coils present within the airpath, are located on the customer's premises. The ownership and maintenance of these assets would therefore be the responsibility of the customer. Maintenance of the heat recovery coils would be conducted in collaboration with TfL Asset Operations. The energy centre would also contain pump sets, controls and other equipment (as detailed in this section) to distribute the heat to and within buildings on the network. Figure 1 shows a very high-level concept of the design, a similar concept to the recently installed heat recovery system at Bunhill Phase 2, City Road.

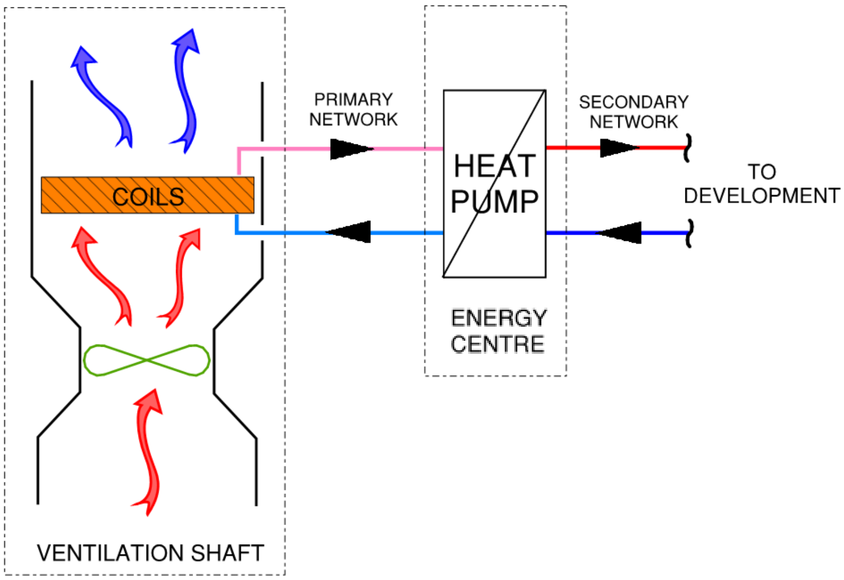

Figure 1: Heat recovery system concept schematic

Retrofitting the coils into TfL ventilation shaft headhouses will require a unique and tailored design for every site. The appropriateness of a given site is dependent on a large number of variables that must be screened initially (See Appendix 3) and then checked throughout the feasibility and subsequent design phases.

Figure 2 provides an example retrofit design for a head house investigated as part of Phase 3 of this study. In heat recovery mode, air is diverted through the coils, which in this case would be hosted in a new structure. If the heat recovery system is not in operation, air exhausts vertically out the top of the head house as per the current design / installation.

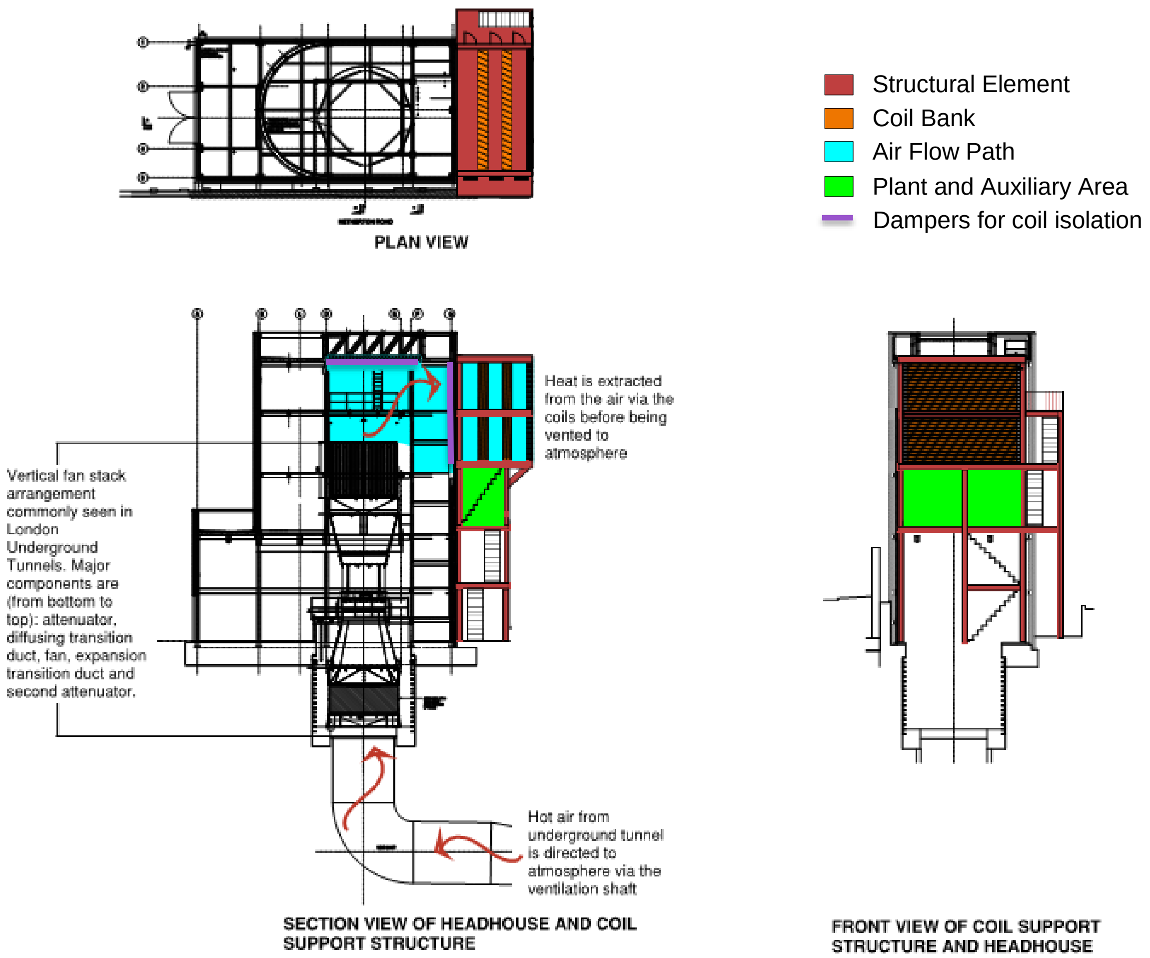

Figure 2: Example head house retrofit design

Pipework routing:
The primary water circuit pipework will be required to be routed between the ventilation shaft building and the energy centre. Due consideration of the potential barriers to pipework installation shall be required, e.g. railway bridges, existing buried services etc

Plant requirements:
If an off-taker chooses to connect to the waste heat recovery system, certain equipment may be required to be hosted in their energy centre which may have not already been considered. The main mechanical plant items required include:

- The water-to-water heat pump and associated noise/vibration enclosure;
- A connection to the electrical grid to run the heat pump and primary pumps, as well as other ancillary power loads. Engagement with UKPN may be necessary to understand the budgetary implications of this connection;
- Primary water circuit pump sets, water treatment, pressurisation units, expansion vessel; and
- Thermal stores to maximise the use of heat available from the heat pump during times of lower demand on the network

Refrigerant:
A variety of different refrigerants can be used in heat pumps. The selection of the most appropriate refrigerant is typically based on the temperature it will be supplying heat at, the cost, as well as safety and permitting considerations.
For heat recovery applications at LU ventilation shafts, the primary choices for refrigerant are Ammonia and Hydrocarbon refrigerants.

Planning implications:
Retrofitting heat recovery coils into TfL ventilation shafts may require significant rework of the buildings within which fans and other equipment are currently hosted. This may have planning implications and will require consideration during design.
There may also be requirements for wayleaves and easements for pipework, other utility routes or additional structures.

Appendix 2: Operational constraints and design considerations

Ventilation shaft assets:
In all cases, systems should be designed in a way that interferes as little as possible with the current and intended operation of TfL ventilation assets. Should there be any fault in the heat recovery system, it should default to normal ventilation operation to ensure that ventilation requirements on the network are met.

Ownership:
TfL does not have an ambition to own additional plant which requires maintenance over and above what is strictly necessary to maintain proper ventilation of the London Underground network. Designs where heat recovery aspects are clearly separated and demarcated from TfL ventilation shaft assets are preferable.

Coil design
The air that is rejected from LU ventilation shafts contains significant levels of particulates that can collect on the surfaces of equipment over which the air passes. As such, coils must be specified that have sufficient spacing between fins (4 fins per inch) to reduce the build-up of dirt and which enable regular cleaning and maintenance. The addition of coils in the ventilation path obstructs the flow of air; fans must be capable of overcoming the additional pressure exerted onto the fans by the coils. The design of LU ventilation equipment must adhere to the noise requirements defined in LU Category 1 S1067 Standard such that nearby homes and businesses are not disturbed.

For optimal heat transfer, the maximum face velocity of the air across the coils must not exceed 2.5 m/s. This means a feasible coil arrangement requires a cross sectional area sufficiently large enough to reduce the air velocity to this level. The coil area also must not be too large such that that air velocity at the face of the coils does not drop below approximately 1 m/s. Dropping below this velocity results in the airflow becoming more laminar, i.e. heat transfer is not as successful over the coils.

It is recommended that the coils should be able to be isolated from the airflow using a motorised damper system, to enable coil cleaning and maintenance. Control mechanisms would be located at the ventilation shaft and will require integration into existing TfL ventilation control systems. Third party requests to operate the damper panels to facilitate coil maintenance will be undertaken alongside representatives from TfL Asset Operations.

Fan Implications:
The installation of the coils will result in an increase in pressure drop which in turn will result in the fan not being able to operate at its designed flow rate. In some instances, this may require a new fan installation. Sites where the existing fan is capable of meeting the additional pressure drop without needing to be replaced, will tend to be viewed more favourably by TfL, unless the fan at that location is due to be renewed anyway.

In some cases, it may be beneficial to operate the fan in reverse to provide cooling to the tube line, though additional cooling is not currently a key driver for TfL in these schemes. In terms of the efficiency of the heat recovery system, operating the fan in reverse is only sensible if the external air temperature is *greater* than the internal temperature of the tunnel, as this will result in a greater COP of the heat pump. However, TfL may consider contracts where additional cooling can be provided to the underground network at a cost to the efficiency of the heat pump, perhaps paying the operator to do so. Further ventilation modelling would be required to determine the impact of reversing fan operation to ensure the operation of the railway is not negatively impacted.

Access:
Separate access to coils (via stairways if necessary) should be included in the design. This will allow the operation and maintenance contractor of the heat recovery system to access the coils for cleaning without needing to enter the ventilation shaft building. Access to the coils can only be undertaken once TfL Asset Operations have isolated the coils from the airpath. This will need to be undertaken by operating the relevant damper panels from the ventilation control panel within the fan room. This will ensure a safe maintenance environment is present to facilitate coil cleaning. Stairways (not ladders) are specified as they provide safe access for contractors carrying cleaning and maintenance equipment.

Noise:
A baseline noise survey will be necessary to obtain more accurate and meaningful information on which to carry-out a more detailed review of noise implications of the heat recovery system. External noise levels for the proposed system shall be calculated to determine if there are any potential issues with system operation for neighbours. The target is for the new system to not exceed background noise levels by minus15bB (with tonality) and minus 10db below otherwise. Clarifications on specific Local Planning Authority planning requirements may need to be sought.

Maintenance:
The maintenance schedule for the proposed heat recovery coils should be consolidated with current maintenance of the existing assets undertaking by the O&M contractor on behalf of TfL. This will help minimise disruption to both normal ventilation of the LU tunnels and the new heat supply system. Maintenance of all other heat recovery assets should be conducted using industry best practices and alongside supplier guidelines and will be the responsibility of the customer.

Asbestos:
There may be risks of asbestos within TfL ventilation shaft buildings and associated assets. The construction plan should be updated to be aligned with the Health and Safety Executives (HSE) Asbestos guidance. This will primarily influence the use of protective equipment, training and waste disposal.

Construction:
Due consideration of the space around the ventilation shaft head houses will be required to ensure that the necessary vehicle access, area for hoarding and storage for materials can be provided during construction.

Appendix 3: Phase 1 & 2 RAG score

Ranked results of Arup's initial scoring assessments are presented in the RAG table below. The site IDs correspond to the map in Appendix 4 and are ranked by their overall assessment score. (Note: only the top 20 sites were taken forward to phase 2, sites that were not carried forward do not have technical and maintenance criteria scores). A feasibility study was conducted on six sites, denoted by a [*] in the table below and shown in Figure 4. Site 1 was not taken forward for reasons discovered after the Phase 1 & 2 scoring.

Within each category were a set of sub-categories, examples of which are given in the description below. As part of the assessment, potential heat receptors were identified for each site. Heat receptor properties also featured in the scoring of sites; those results are not included in this table.

Site ID	Postcode	Access	Space	Existing Asset	Technical	Maintenance
		Land ownership *Access constraints* *Noise receptors* *Transport disruption*	*Coil location* *Space within headhouse*	*Fan condition* *Temperature* *Flow rate*	*Ventilation shaft area* *Fan condition* *Energy centre size requirements*	*Asbestos* *Ease of maintenance*
1	NW1 2DU	Green	Green	Amber	Green	Amber
2*	N15 6RD	Green	Green	Green	Amber	Green
3*	SW1V 2NS	Green	Green	Amber	Green	Green
4*	E3 2TY	Green	Green	Amber	Green	Amber
5*	SE11 4PP	Green	Amber	Green	Green	Amber
6*	SE1 6AZ	Green	Amber	Amber	Green	Amber
7*	N15 3JA	Green	Green	Amber	Amber	Amber
8	N15 4AL	Green	Green	Green	Green	Amber
9	N5 1LX	Green	Green	Green	Green	Green
10	SW12 9BS	Green	Green	Green	Green	Amber
11	N1 0AZ	Green	Green	Amber	Green	Amber
12	NW8 8TS	Green	Amber	Green	Green	Red
13	N6 5BH	Green	Green	Amber	Green	Amber
14	SW8 1JX	Green	Green	Green	Green	Green
15	SW9 8AF	Amber	Green	Green	Green	Green
16	E1 4EH	Amber	Amber	Amber	Green	Amber
17	WC1X 9EA	Green	Green	Amber	Amber	Amber
18	SW9 8ND	Green	Amber	Amber	Green	Green
19	SW4 9DS	Amber	Green	Green	Green	Amber
20	SW4 6JW	Green	Green	Amber	Green	Amber
21	N4 2DH	Green	Green	Green	-	-
22	N1 9AL	Green	Amber	Amber	-	-
23	SE1 7XG	Green	Amber	Amber	-	-
24	W1R 1RF	Amber	Amber	Green	-	-
25	NW5 2AA	Green	Green	Green	-	-
26	NW3 6HY	Green	Green	Amber	-	-
27	N7 7JW	Green	Green	Amber	-	-
28	SE1 7ND	Amber	Amber	Green	-	-

Site ID	Postcode	Access	Space	Existing Asset	Technical	Maintenance
29	SE1 9SP				-	-
30	N1 9AL				-	-
31	SE1 6LW					
32	N17 9DF					
33	W11 4SY				-	-
34	WC2H 0AP				-	-
35	N1 0RD				-	-
36	N19 5RQ				-	-
37	EC2M 6TX				-	-
38	NW1 5HA				-	-
39	WC2B 6AA				-	-
40	SW1E 5HS				-	-
41	W1J 5QG				-	-
42	W1B 3AG				-	-
43	W1S 5LD				-	-
44	NW1 8NH				-	-
45	W1V 9LB				-	-
46	EC2 3BA				-	-
47	WC1V 6DR				-	-
48	W1W 5BB				-	-
49	NW1 5HA				-	-
50	E2 9QP				-	-
51	W11 3HS				-	-
52	NW1 5LJ				-	-
53	W1J 7AS				-	-
54	W1R 1FE				-	-
55	SW7 4XA				-	-

Appendix 4: Ventilation shaft locations

The map in Figure 3 shows the approximate locations of ventilation shaft head houses with IDs corresponding to those in the table in Appendix 3.

The size of the circle represents the site specific ‘buffer’ zone: the potential area within which a heat demand could viably connect to the waste heat source. The size of this area is calculated using the amount of heat available, an assumed price of heat in line with market expectations, a typical cost per meter of distribution pipework and a conservative payback period. Whether a load within the zones is viable for connection is subject to further, connection specific assessment that has not been undertaken for any sites except those investigated in Phase 3.

Sites considered to be most suitable for connection will be those in close proximity to the ventilation shaft, have a high heat demand, have low heating supply temperatures, space for hosting equipment and a desire/requirement to provide low carbon energy to those customers/residents/businesses connected.

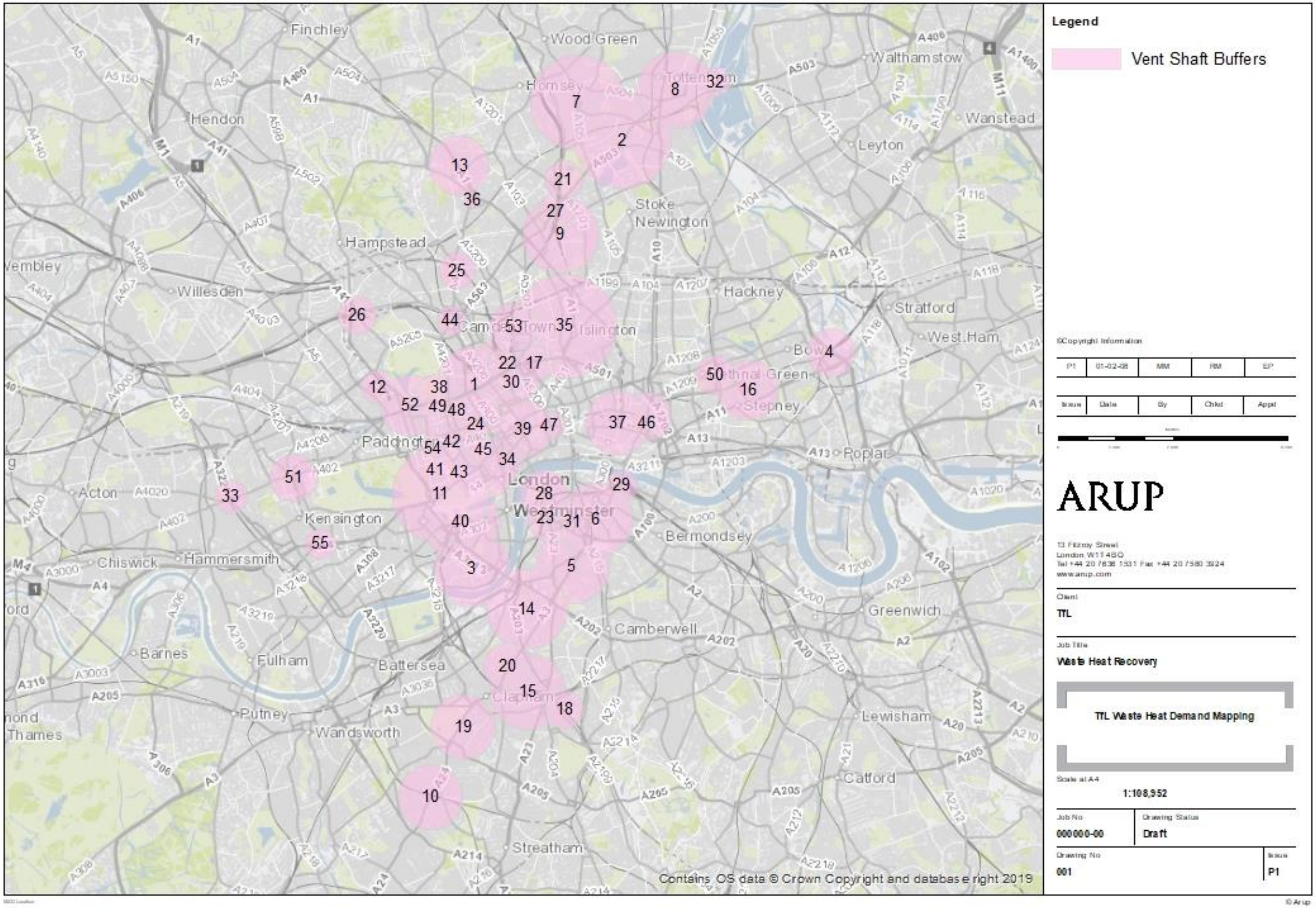

Figure 3: Ventilation shaft locations and 'buffer' zones

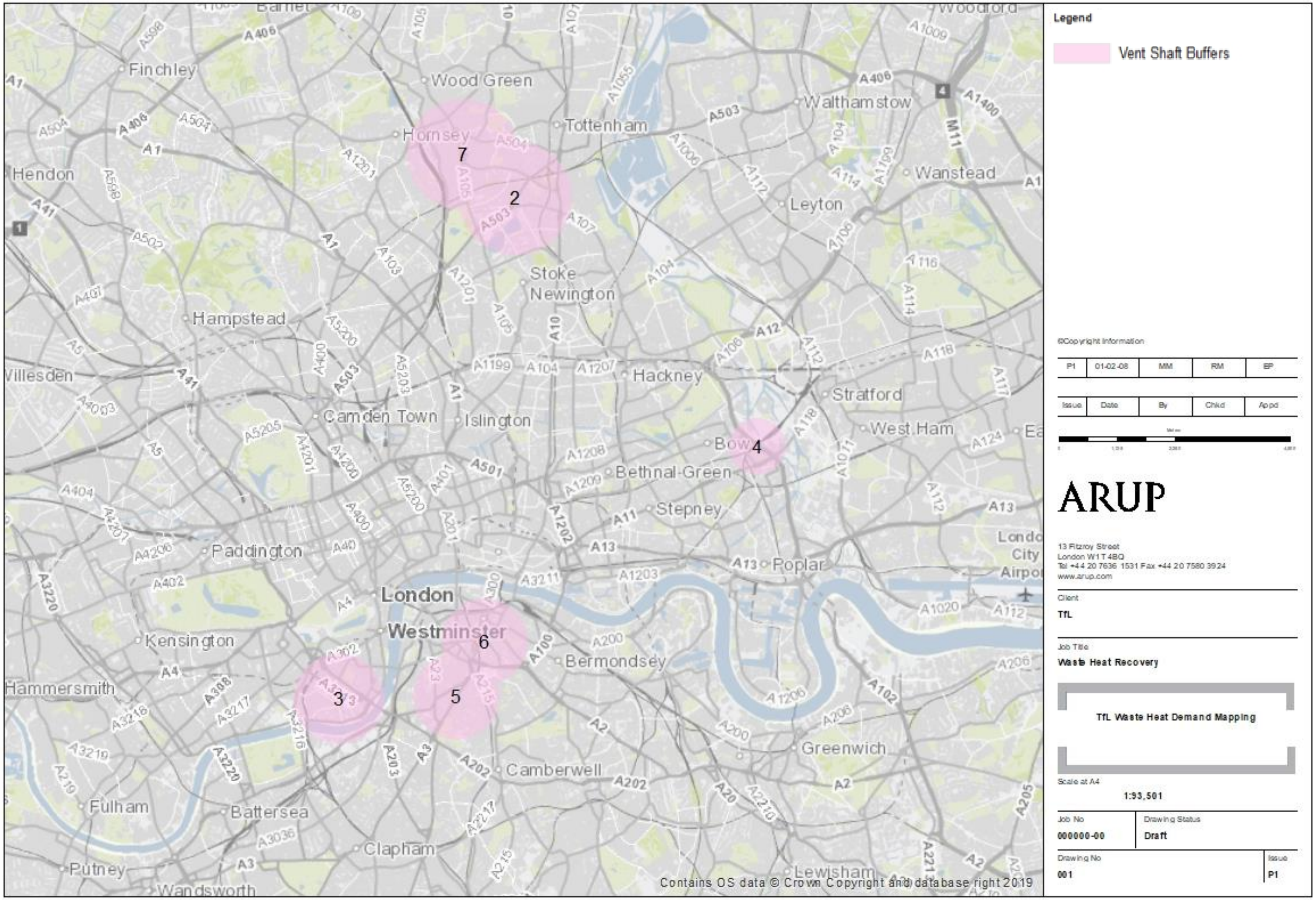

Figure 4 Phase 3 ventilation shaft locations and 'buffer'zones

Appendix 5: Phase 3 Feasibility findings

The six best scoring sites from the Phase 1&2 assessment (IDs 2 – 7) are currently undergoing feasibility study to test their technical, operational and financial performance, alongside how they might be constructed and delivered.

The six sites scored particularly high due to there being a large, potentially interested heat recipient for the low carbon heat in close proximity to the ventilation shaft.

Concept designs of systems were based on the ventilation shaft assets, the necessary route for pipework and technical details of the potential heat off-taker. High-level capital costs and system efficiencies were estimated, maintenance and access requirements were summarised and routes to delivery highlighted.

Many findings are still in draft for these sites, and results are highly dependent on the nature and location of the heat recipient. The table below provides a summary of some of the key technical and financial outputs of the Phase 3 studies.

Phase 3 Feasibility study key details	
Ventilation shaft flow rate	47 – 100 m^3/s
Nominal heat pump output capacity	0.6 - 1.5 MW
Primary water circuit flow / return temperature	11/6°C
Heat pump output temperatures	60-85°C
Seasonal heat pump Coefficient of Performance (COP)	2.8 - 3.6
Heat pump annual output (depends on development consumption / demand profile)	5 - 10 GWh/annum
System capital cost (excluding pipe network costs)	£2.5 - 4.5m (+/- ~50%)
Pipe network cost (assuming plastic pipe, distributed at primary water circuit temps)	£960 - 1,600 / m

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