Programme Area: Distributed Energy

Project: Macro DE

Title: D.H.N. Design and Algorithm Verification

Abstract:

This work has been carried out as part of the ETI's wider Macro Distributed Energy (DE) research project to understand the economics and therefore the opportunities for DE across the UK. Understanding the capital cost (CAPEX) of District Heating Networks (DHN) is an important part of that process as the networks typically represent 60% of the capital cost of a scheme. The work combines a statistical approach with detailed design modelling tools incorporating GIS mapping data and cost data from recent UK DHN projects. The economic case for Macro-DE in Great Britain (GB) is being assessed by carrying out detailed economic and energy modelling for 20 Characteristic Zones. The results from these zones will then be extrapolated to GB as a whole.

Context:

This project quantified the opportunity for Macro level Distributed Energy (DE) across the UK and accelerate the development of appropriate technology by 2020 for the purposes of significant implementation by 2030. The project studied energy demand such as residential accommodation, local services, hospitals, business parks and equipment, and is developing a software methodology to analyse local combinations of sites and technologies. This enabled the design of optimised distributed energy delivery solutions for these areas. The project identified a number of larger scale technology development and demonstration projects for the ETI to consider developing. The findings from this project is now being distilled into our Smart Systems and Heat programme. The ETI acknowledges that the project was undertaken and reports produced by Caterpillar, EDF, and the University of Manchester.

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Mooney Kelly NIRAS

Energy Technologies Institute

Macro DE

D.H.N. Design and Algorithm Verification

REPORT Rev. 5

May 2012

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List of General Abbreviations

AHD	Area Heat Density
CZ	Characteristic Zone
DE	District Energy
DH	District Heating
DHN	District Heating Network
DHP	District Heating Plant or Energy Centre
E	Energy
E_{HL}	Heat Loss
E_{PE}	Pumping Energy
HIU	Hydraulic Interface Unit
LHD	Line Heat Density
LPHD	Line Peak Heat Density
MLSOA	Middle Layer Super Output Area
SEM	Standard Error of Mean

List of Simplified Algorithm Abbreviations

COD_D	Cost of distribution pipes for dwellings [£/m]
COD_I	Cost of distribution pipes for tertiary [£/m]
COH	Cost of hydraulic interface unit for dwellings [£/connection]
COI	Cost of hydraulic interface unit for tertiary [£/connection]
COT	Cost of transmission pipes [£/m]
HD	Heat demand [MWh]
LOD_D	Length of distribution pipes for dwellings [m/MWh]
LOD_I	Length of distribution pipes for tertiary [m/MWh]
LOT	Length of transmission pipes [m/MWh]
NOD	Number of connections to dwellings [connections]
NOI	Number of connections to tertiary [connections]
TC	Total cost [£]

List of Detailed Algorithm Abbreviations

COD_I	Cost of distribution pipes for tertiary [£/m]
COD_{TY}	Cost of distribution pipes by type [£/m]
COH	Cost of hydraulic interface unit for dwellings [£/connection]
COI	Cost of hydraulic interface unit for tertiary [£/connection]
COT	Cost of transmission pipes [£/m]
LOD_I	Length of distribution pipes for tertiary [m/connection]
LOD_{TY}	Length of distribution pipes by dwelling type [m/connection]
LOT	Length of transmission pipes [m]
NOD	Number of connections to dwellings [connections]
NOD_{TY}	Number of connections by dwelling type [connections]
NOI	Number of connections to tertiary [connections]
TC	Total cost [£]

List of TERMIS Approach Abbreviations

COD_{TY}	Cost of distribution pipes by building (dwelling/tertiary) type [£/m]
COH_{TY}	Cost of hydraulic interface unit by building (dwelling/tertiary) type [£/connection]
COT_{PT}	Cost of transmission pipes by pipe type [£/m]
LOD_{TY}	Length of distribution pipes by building (dwelling/tertiary) type [m/connection]
LOT_{PT}	Length of transmission pipes by pipe type [m]
NOD_{TY}	Number of connections by building (dwelling/tertiary) type [connections]
TC	Total cost [£]

List of Revised TERMIS Approach Abbreviations

COD_{TY}	Cost of distribution pipes by building (dwelling/tertiary) type [£/m]
COH_{TY}	Cost of hydraulic interface unit by building (dwelling/tertiary) type [£/connection]
COT_{LPHD}	Cost of transmission pipes (function of Line Peak Heat Density) [£/m]
LOD_{TY}	Length of distribution pipes by building (dwelling/tertiary) type [m/connection]
LOT_{ETI}	Length of main roads from ETI data [m]
LOT_{F}	Conversion factor (function of Line Heat Density) [-]
NOD_{TY}	Number of connections by building (dwelling/tertiary) type [connections]
TC	Total cost [£]

1 EXECUTIVE SUMMARY

This work has been carried out as part of the ETI's wider Macro Distributed Energy (DE) research project to understand the economics and therefore the opportunities for DE across the UK. Understanding the capital cost (CAPEX) of District Heating Networks (DHN) is an important part of that process as the networks typically represent 60% of the capital cost of a scheme. The work combines a statistical approach with detailed design modelling tools incorporating GIS mapping data and cost data from recent UK DHN projects.

The economic case for Macro-DE in Great Britain (GB) is being assessed by carrying out detailed economic and energy modelling for 20 Characteristic Zones. The results from these zones will then be extrapolated to GB as a whole.

The purpose of this report is to document the results obtained from District Heating Network (DHN) modelling of a sample comprising of three Characteristic Zones (CZs) containing 16 Middle Layer Super Output Areas (MLSOAs) in total. The purpose of carrying out DHN modelling in the Macro DE project is to verify the proposed Macro DE Cost Algorithm and determine any unknown factors to be able to confidently extrapolate results for the remaining characteristic zones which will not be individually modelled. The costs calculated for each CZ will then be used to establish the GB benefits case for DHNs. An additional benefit of the DHN modelling is the associated calculations of heat loss and required pumping energy which also has been included in the analysis.

The DHN modelling tool TERMIS, which includes both hydraulic and thermodynamic modelling of DHN networks, has been used for the analysis.

DHN models have been built for three CZs containing a total of 16 MLSOAs. They cover a representative range of the total population consisting of 20 CZs with 91 MLSOAs. The models are created as preliminary models based on a 1:1 transformation of GIS road centre lines into a DHN followed by a manual review to correct anomalies arising from some minor limitations of this automated approach.

Baseline data for the CZs/MLSOAs for area, annual heat demand and peak heat demand originating from the WP2 heat demand analysis have been applied to the various purposes (scenarios) of the simulations.

The main results obtained can be listed as:

- Sample CZs have been assessed as being representative for the population.
- The lower limit for ground-floor plan area of buildings to be connected to the DHN has been established at 30 m². This criterion is derived from UK planning guidance and actual data.
- A relationship between Area Heat Density (AHD) and Length of Distribution pipe (LOD) has been established for dwellings and tertiary buildings with a high level of confidence.

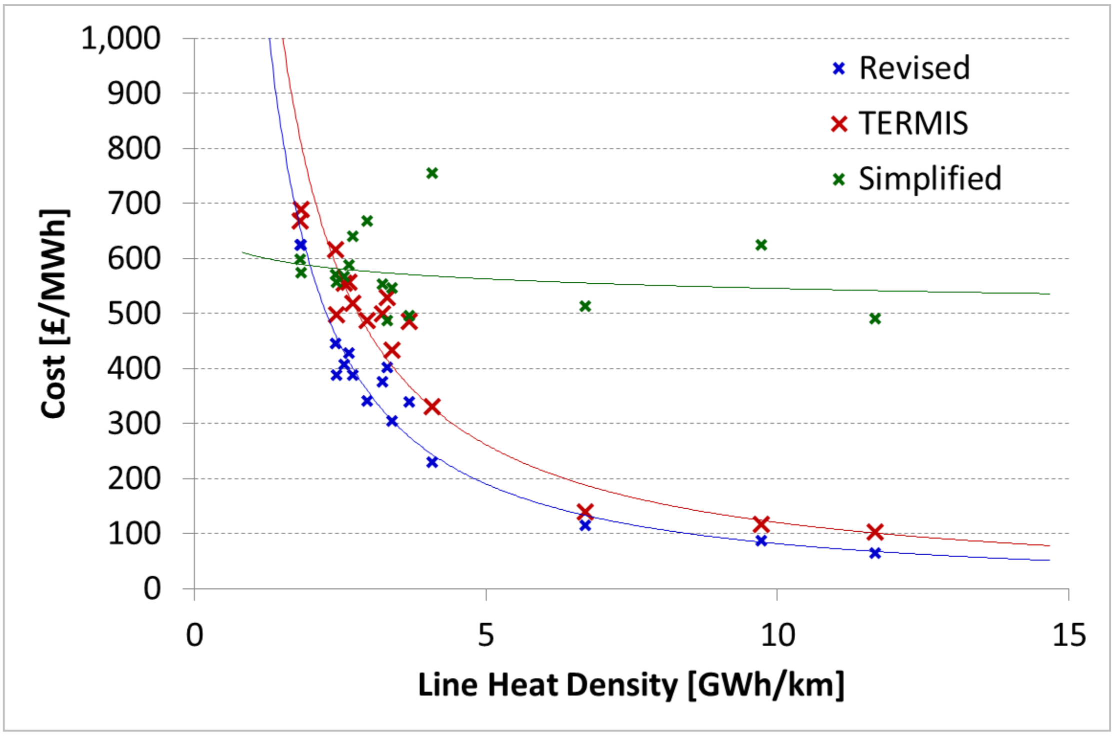
- A relationship between Line Heat Density and ratio of GIS-derived road length to Length of Transmission pipe (LOT) has been established with a high level of confidence.
- Cost book for a range of pipe sizes established, sizing of transmission pipes conducted and costs calculated.
- Relationship between Line Peak Heat Density and Cost of Transmission (COT) pipes has been established with a high level of confidence.
- Revised approach of the Detailed Algorithm established based upon the results of LOD, LOT and COT.
- Relationship between Line Heat Density and Heat Loss of the transmission system has been established with a high level of confidence.
- The pumping Power Requirement has been calculated for the three CZs as a function of Line Heat Density. The results are in line with reference data from Danish DHN published statistics on actual schemes.

Overall Conclusions

The relationships derived show that the Revised Algorithm as now constructed will provide a suitable method for estimating costs for all CZs using cost book data derived for the UK and based on actual DH designs produced using standard design software for 3 sample areas in the UK.

There is a strong relationship with line heat density and the use of GIS data on road length together with statistics on fuel use in a given area would enable a first estimate of DH costs to be made for any MLSOA in the UK.

As the Figure below shows the TERMIS curve which represents the costs for schemes using actual designs and the Revised Algorithm costs which assumes an 80% market penetration and shared connections for terraces and semi-detached houses. This is a significant improvement on the accuracy of the Simplified Algorithm which was derived from more limited data and over estimated costs in high density areas.



Revised Cost Algorithm for District Heating Network capital costs

2 INTRODUCTION OF SCOPE

The scope of work for the DHN modelling is described under variation 2, which includes stage 3 and stage 4, in the document:

> ETI Macro Distributed Energy Project
> Proposal for Variation 1 and 2 related to District Heating Network Algorithm
> Version 6 August 5th 2011

The scope is summarized as follows:

- Stage 3 - produce preliminary network designs using DH design software (TERMIS) for three CZs from which costs can be estimated for a range of heat densities using the costs from stage 1 (the cost book), Ref. 1.
- Stage 4 - analyse the costs obtained in Stage 3 to derive relationships that can be used to estimate the parameters in the cost algorithms, Ref. 1, and hence provide cost estimates for the remaining CZs.

The workflow of the scope is illustrated in Figure 2-1.

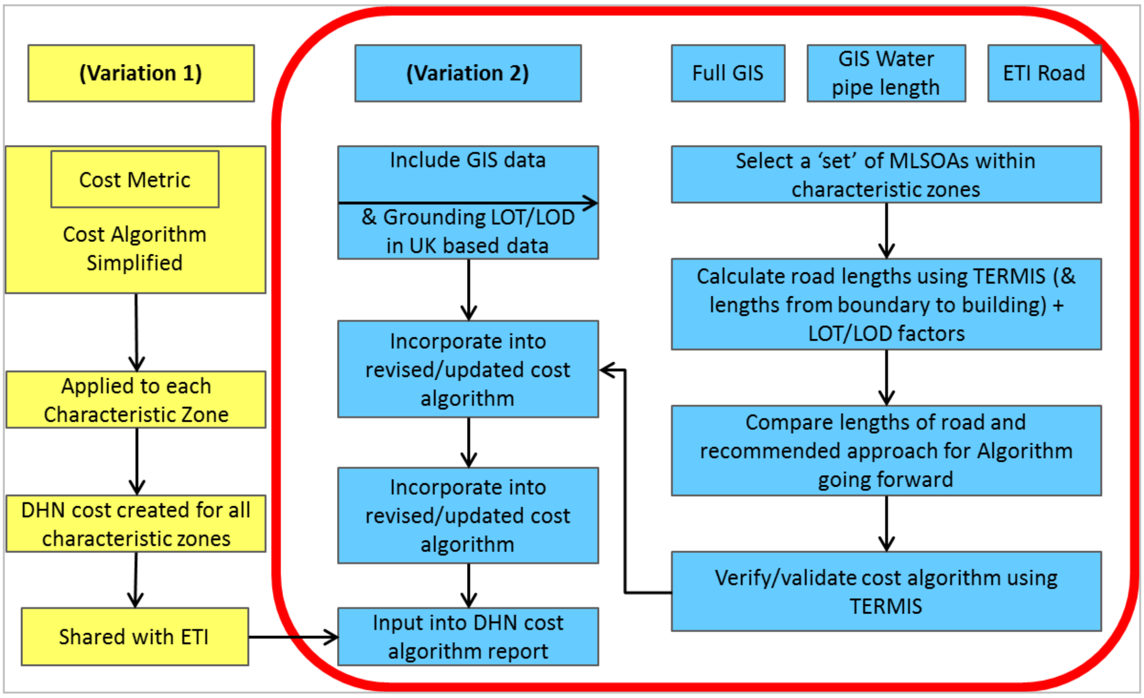


Figure 2-1: Scope workflow.

The approach is to produce a DHN design for three CZs which will be strategically selected to cover a representative range of heat densities on MLSOA level for a total of 15 - 20 MLSOAs from which relationships then can be derived.

Heat Demand, Peak Heat Demand, Area, Households and Road Length (as provided by the ETI) are already available within the consortium on MLSOA level for all CZs. Area Heat Density (AHD) and Line Heat Density (LHD) have additionally been calculated for each MLSOA, where LHD is defined as heat demand per km of GIS road length. Thereby a representative sample of MLSOAs can be selected.

The Road Length data are readily available from ETI and are intended for future use for estimating the length of Transmission pipes within each MLSOA. It will be an additional task within this scope to compare these to the road lengths as derived from the full GIS which is used for the DHN modelling. Note that the originally additional planned use of GIS Water Pipe Length was not used in the early stages of the scope as this data turned out to be impracticable to collect.

The following statement has been received from ETI which describes how the ETI Road Length data has been derived:

The MLSOA road length data was derived from two freely-available GIS datasets published by Ordnance Survey: Meridian2 and VectorMap. Using GIS software these datasets were combined with the boundaries for middle layer census super output areas (MLSOAs) to calculate the length of road in each area.

Meridian2 was found to be suitable to derive the length of major roads (A, B and M roads) because it represents all roads as a simple line feature, avoiding double counting of dual carriageways, slip roads etc. However, being a high-level dataset intended for UK-wide analysis, Meridian2 was found to have insufficient resolution of minor roads to give accurate estimates of minor road length in individual MLSOAs. For minor roads estimates were therefore derived in the same manner from the VectorMap dataset, a much higher resolution product. The approach and derivation were verified by comparison to statistics on road lengths per local authority published by DfT (http://www.dft.gov.uk/statistics?post_type=table&series=road-lengths-series)

The DHN design is semi-automatically generated by the use of GIS based data of road centre lines, buildings, MLSOA boundaries and elevations. The GIS data was supplied from:

http://www.emapsite.com/

The combined data sets are used to generate the topology of the preliminary DHN in the TERMIS software package, allocate heat demand and assign a location for the DH Plant (Energy Centre). In addition to the GIS road centre lines used for the DHN modelling road lengths at the MLSOA level as supplied by ETI will be used in developing the relationships.

The DHN models are then used for pipeline dimensioning, pipeline cost calculation, heat loss calculation and pumping energy requirement calculations for the for the transmission pipeline system.

Key data, findings and results are extracted from the complete process and conclusions and recommendations are documented.

3 WORK PROCEDURE

The works have been conducted by following the procedures as described in the following sections 3.1 - 3.5.

3.1 Sample Selection

Select the CZs to be used for the DHN so that an appropriate coverage of the energy density range on MLSOA level for the full population is achieved. The sample size is assumed to be adequate if it includes 15-20 MLSOAs, refer to12.1.1 Assumption1 - Sample Size. for more details.

At the same time the distribution of the sample by energy density should be close to the distribution of energy density of the population. This is checked by plotting frequency diagrams for both the sample and the population; these plots should then cover the entire energy density spectrum for plots with similar frequency distributions.

3.2 Data Preparations

A basic check of GIS data extracted is carried out for each CZ which cover road centre lines, buildings, MLSOA borders and ground elevations. This check has focused on verifying the consistency of the topology and the relationships between layers where required.

The road centre poly-lines from GIS need to be verified for consistency before being converted to a DHN. A manual visual process is carried out to eliminate errors. Where the centre line of roads translate into impractical layouts e.g. a loop following a roundabout, these are broken or excluded, double lines are deleted and major energy transport paths are identified in order to accommodate the location of the District Heating Plant (DHP) within the model. Detached roads (pipes), mainly at MLSOA boundaries, are attached by manually adding extra roads and excess roads (pipes) are deleted. Roads and buildings were affiliated to an MLSOA.

The buildings polygons from GIS are converted to DH demand points using the building centre point as location and ground-floor plan area as a basic metric for expected heat demand for the individual building. Based on building sizes each building is assigned to one of three classes, Out House, Dwelling or Tertiary; refer to 12.1.2 Assumption 2 – Building Classification for more details.

3.3 Model Build & Configuration

The DHN is considered to consist of three primary elements:

- The transmission pipe system which generally is installed along the roads.
- The distribution pipe system which connect the buildings to the transmission pipe system.

- The equipment needed to connect the buildings to the DHN typically comprising control valves, heat meters and heat exchangers and collectively described as the hydraulic interface unit or HIU.

The modified GIS data for each CZ is converted to a unified DHN model covering the transmission pipes only. One model for each CZ, each model contains several scenarios.

Additional checks and corrections are performed after model generation with focus on a hydraulic and thermodynamic consistent layout. This includes further deletion of pipes for efficiency purposes. Valves are introduced to close critical loops that hinder localisation of the main pipes in the transmission network. For efficiency purposes pressure zones, if any, are identified and hydraulically isolated using valves and/or boosters pumps at the connecting pipes.

Demand data is added by using the given heat loads for each MLSOA scaled onto the demand point by use of the associated building size. Average annual heat demands, seasonal heat demands and peak heat demands are added to the model as a catalogue which enabled the model to easily shift between different load scenarios. Customer demand data is then added to the transmission system by locating the nearest transmission pipe and affiliating the customer demand. The “line” used to affiliate a demand to a transmission pipe is assumed to be a good representation for the associated distribution pipe, the length of this distribution pipe is transferred to the demand point as an extra attribute.

A pipe type catalogue (cost book) is established from Ref. 1, pipe dimensioning criteria defined and a DHP added.

3.4 Scenarios & Simulations

A number of scenarios are defined and configured for each CZ and associated simulations conducted before results are extracted and reported.

The first scenarios to be simulated are the pipe dimensioning scenarios, which assigns optimal pipe types to each pipe segment based on the pipe type catalogue and the dimensioning criteria. The results of the pipe dimensioning are updated to the model and reused in the following scenarios.

The remaining scenarios are created to calculate heat loss and pumping power requirement. These scenarios are created per season for summer, winter and transition. These scenarios are further detailed by introducing diurnal curves for the variation over a single day. Diurnal curves for weekday and weekend day are available resulting in a total of 18 scenarios.

All in all 7 scenarios are created for each CZ.

3.5 Results Analysis

Input and output data from the data preparation, model configuration and scenario simulations is exported and collated in relevant results tables. Based on the results tables plots of expected relationships are created to check, verify and establish adequate relations with good/high confidence.

Empirical relationships are analysed for LOD, LOT, COT, Heat Loss and Pumping Power Requirement as a function of AHD, LHD, AHPD or LPHD. Confidence levels of the relations observed are evaluated by the SEM, where SEM below 20 % will be considered as good confidence in order to accept a relation and a SEM below 10 % will be considered as high confidence.

All results are summarized in the Technical Conclusion, section 10,

4 SAMPLE SELECTION

A normalized frequency diagram of the 91 MLSOAs contained in the 20 CZs has been produced, both with Area Heat Density and Line Heat Density as basis, ration of annual heat demand by area and road length for each MLSOA level, described in more detail in section 8. Both plots display a Log Normal nature, see Figure 4-1 and Figure 4-2.

Both AHD and LHD are calculated at a level of resolution based on the MLSOA dataset. AHD is therefore calculated from the estimated heat demand in an MLSOA (as derived in WP2) divided by the total geographic area of the MLSOA. LHD is calculated from the estimated heat demand in an MLSOA divided by the total road length in the area. This road length has been taken as the unadjusted road lengths provided by the ETI (see section 2 page 9).

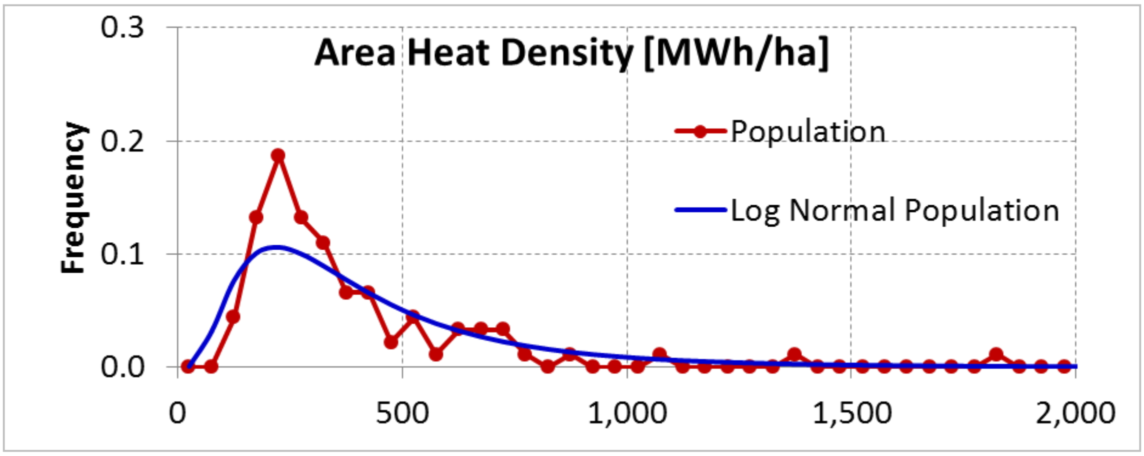


Figure 4-1: Frequency diagram of AHD for MLSOA population.

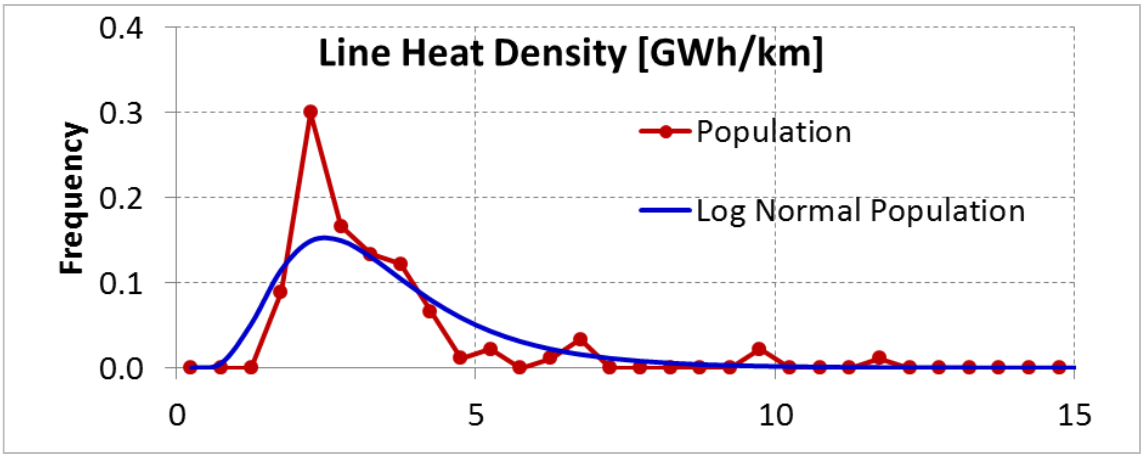


Figure 4-2: Frequency diagram of LHD for MLSOA population.

Three CZs have been identified which cover a wide range of energy density, (AHD and LHD), and contain 16 MLSOAs in total. The basic data for these CZs and for each MLSOA are detailed in sections 4.1 - 4.3 and verified as a representative sample in section 4.4.

4.1 CZ 70 Harrow - West London Area

CZ 70 is located in the West London Area and contains 6 MLSOAs as shown in Figure 4-3.

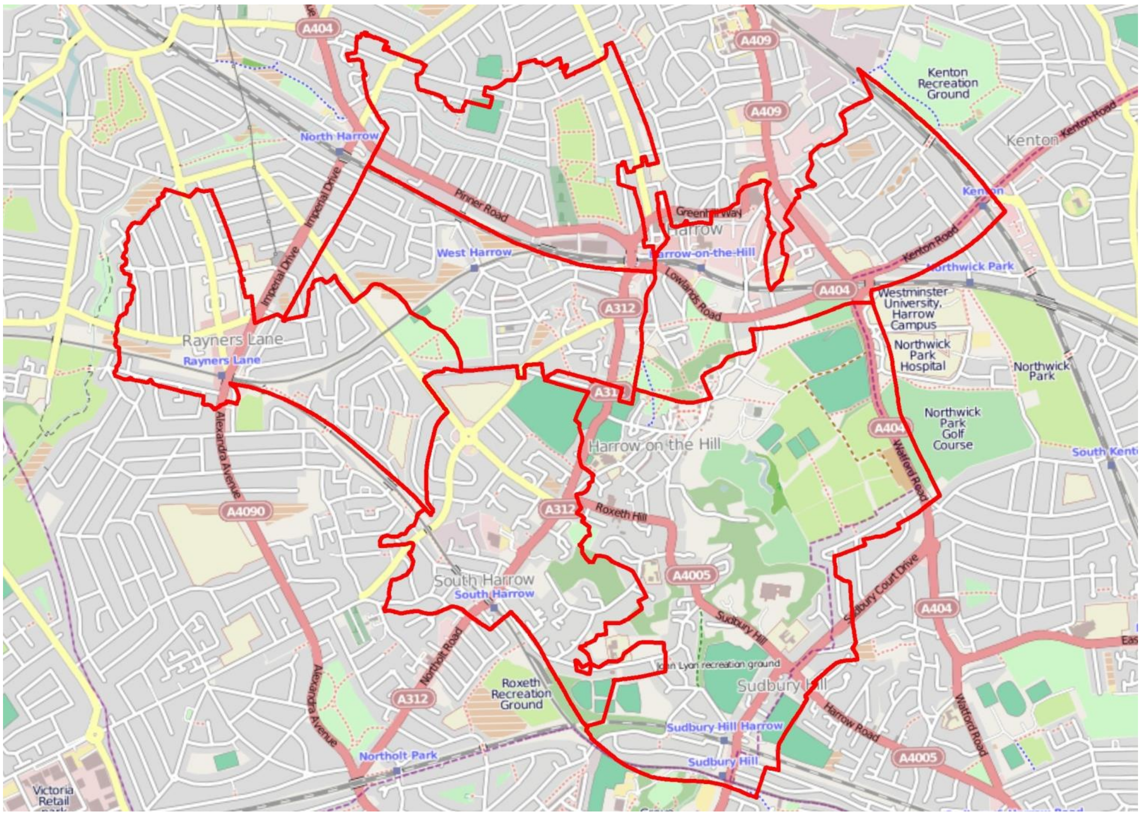


Figure 4-3: Location and layout of CZ 70 Harrow.

Basic data available are listed in Table 4-1.

	Input								
MLSOA	Annual Heat Demand	Heat Demand Fraction	Peak Heat Demand	Land Area	Population	Households	Heat Density Area	Heat Density Line	Road Length ETI
[Name]	[GWh]	[#]	[kW]	[ha]	[#]	[#]	[MWh/ha]	[GWh/km]	[km]
Harrow 021	40.6	0.15	16,000	103	6,289	2,464	394	3.24	12.54
Harrow 023	63.7	0.24	24,200	123	6,231	2,805	518	4.09	15.58
Harrow 024	36.7	0.14	14,800	93	6,420	2,510	395	3.32	11.04
Harrow 025	38.3	0.14	15,600	116	6,078	2,267	330	2.72	14.06
Harrow 027	43.8	0.16	16,600	120	6,218	2,627	365	3.69	11.87
Harrow 029	46.5	0.17	16,600	266	6,089	2,623	175	2.97	15.67
Total Zone	**269.6**	**1.00**	**103,800**	**821**	**37,325**	**15,296**	**328**	**3.34**	**80.76**

Table 4-1: Basis input data for CZ 70 Harrow.

4.2 CZ 148 Westminster - Central London Area

CZ 148 is located in the Central London Area and contains 3 MLSOAs as shown in Figure.

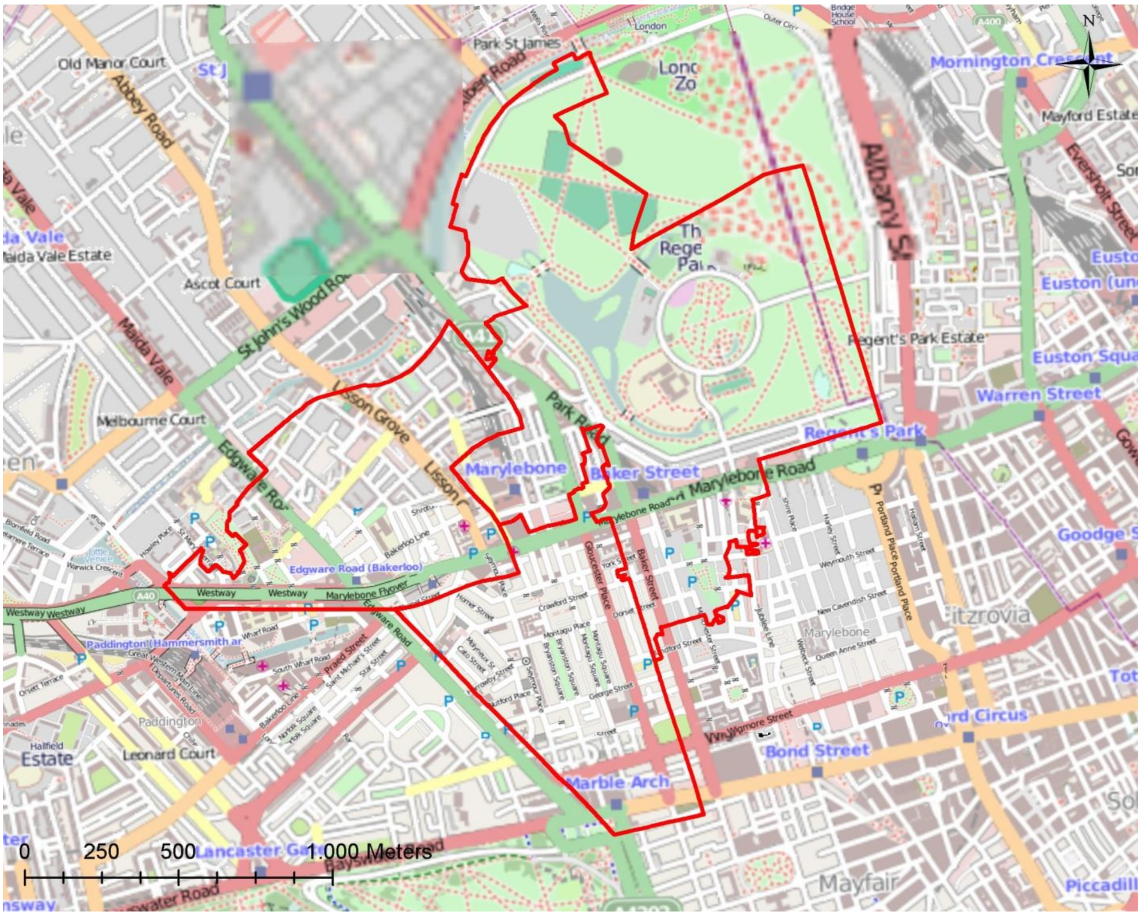


Figure 4-4: Location and layout of CZ 148 Westminster.

Basis data available are listed in Table 4-2.

	Input								
MLSOA	**Annual Heat Demand**	**Heat Demand Fraction**	**Peak Heat Demand**	**Land Area**	**Population**	**Households**	**Heat Density Area**	**Heat Density Line**	**Road Length ETI**
[Name]	**[GWh]**	**[#]**	**[kW]**	**[ha]**	**[#]**	**[#]**	**[MWh/ha]**	**[GWh/km]**	**[km]**
Westminster 008	153.5	0.41	63,100	141	6,215	3,267	1,089	11.68	13.14
Westminster 009	83.0	0.22	28,900	61	8,327	3,463	1,361	6.72	12.35
Westminster 012	137.6	0.37	53,500	54	7,533	3,856	2,548	9.73	14.15
Total Zone	**347.1**	**1.00**	**144,800**	**256**	**22,075**	**10,586**	**1,462**	**9.44**	**39.64**

Table 4-2: Basis input data for CZ 148 Westminster.

4.3 CZ 313 Solihull - South East Birmingham Area

CZ 313 is located in the South East Birmingham Area and contains 7 MLSOAs as shown in Figure 4-5.

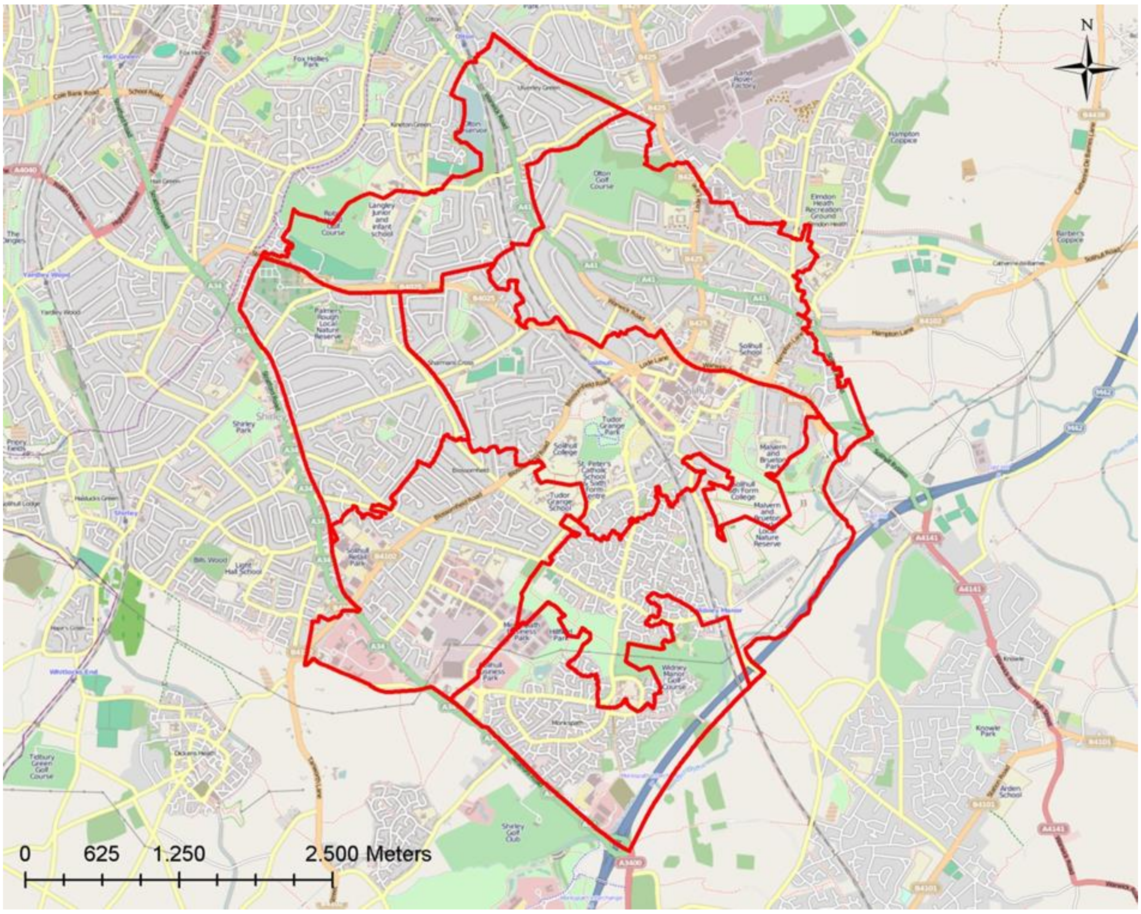


Figure 4-5: Location and layout of CZ 313 Solihull.

Basis data available are listed in Table 4-3.

	Input								
MLSOA	**Annual Heat Demand**	**Heat Demand Fraction**	**Peak Heat Demand**	**Land Area**	**Population**	**Households**	**Heat Density Area**	**Heat Density Line**	**Road Length ETI**
[Name]	**[GWh]**	**[#]**	**[kW]**	**[ha]**	**[#]**	**[#]**	**[MWh/ha]**	**[GWh/km]**	**[km]**
Solihull 014	39.8	0.09	14,200	226	5,578	2,258	176	2.44	16.28
Solihull 016	81.4	0.18	28,200	366	9,104	3,697	222	2.58	31.49
Solihull 018	66.8	0.15	23,900	218	8,730	3,606	306	2.67	25.05
Solihull 019	79.3	0.18	27,100	382	6,155	2,522	207	2.45	32.33
Solihull 022	96.3	0.22	33,300	288	8,027	3,315	334	3.40	28.34
Solihull 024	41.2	0.09	13,800	273	6,111	2,307	151	1.84	22.42
Solihull 027	39.4	0.09	13,000	240	5,805	2,207	164	1.82	21.64
Total Zone	**444.2**	**1.00**	**153,300**	**1,993**	**49,510**	**19,912**	**223**	**2.50**	**177.55**

Table 4-3: Basis input data for CZ 313 Solihull.

4.4 Sample Verification

The data of the sample has been added to the frequency diagrams and the results are seen in Figure 4-6 and Figure 4-7.

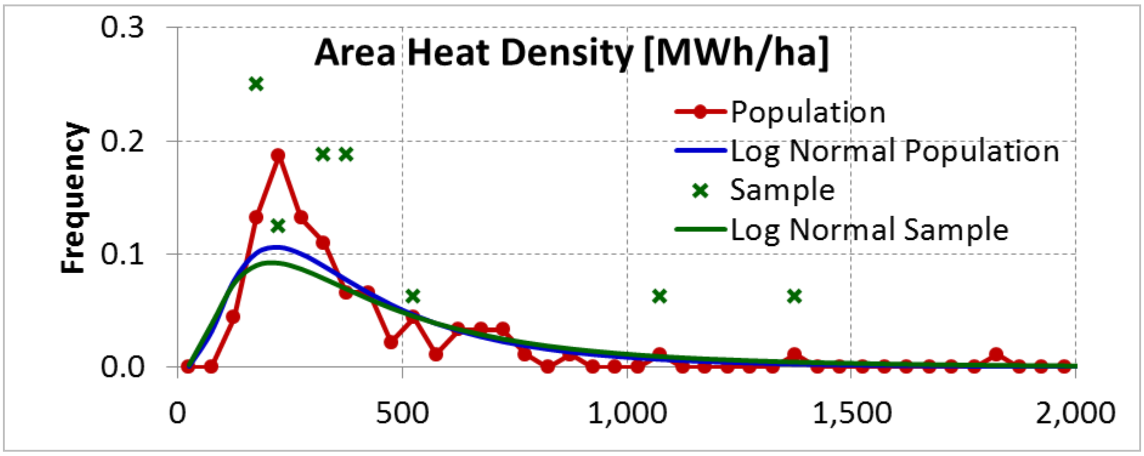


Figure 4-6: Frequency diagram of AHD for MLSOA sample and population.

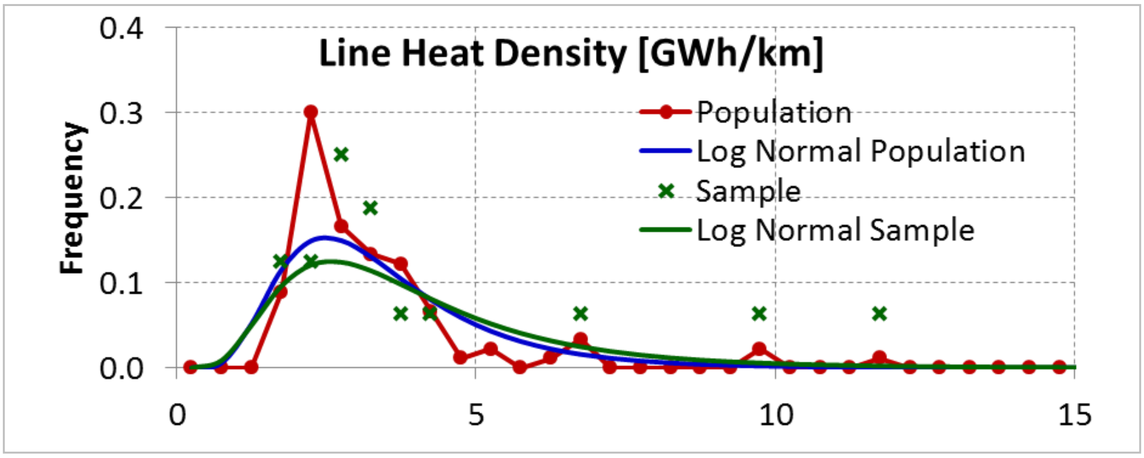


Figure 4-7: Frequency diagram of LHD for MLSOA sample and population.

The result of a carefully matched sample, as opposed to a random selected sample, is clear as this relatively small sample size will represent the population quite well. This is seen from both Figure 4-6 and Figure 4-7 the log normal frequency associated with the sample is almost identical to the log normal frequency for the population and the sample is therefore assumed to be representative for the population. Refer to 12.1.1 Assumption1 - Sample Size. for more details on sample size assumptions. This could be further verified by performing a statistical test on the hypothesis that the sample mean and/or variance is identical to the population mean and/or variance. Such test falls outside the current scope of work.

5 DATA PREPARATIONS

The received GIS data have, for each CZ included in the sample, been validated for compatibility and flaws/inconsistencies using MapInfo (Pitney Bowes Software) and Model Manager (the model building tool associated with TERMIS, 7-Technologies/Schneider Electric). Thereafter the adjusted/corrected GIS data has been adapted using both programs for construction of a DHN model for each sample CZ.

5.1 Data Validation

The GIS data used for each of the selected CZs covers roads, road centre lines, buildings, MLSOA borders and ground elevations.

The data sources provided for the Harrow sample area (other areas are similar) were:

File Name	**Provider/Data description**
Harrow_Areas	Office for National Statistics/MLSOA boundary shapefiles
BoundaryLine	Emapsite/ OS Mastermap shapefile
TQ_Road_Clip	Opendata/ Meridian 2 shapefile
TopographicArea	Emapsite/ OS Mastermap shapefile
MinorRd	Opendata/ Meridian 2 shapefile
TopographicLine	Emapsite/ OS Mastermap shapefile
TopographicPoint	Emapsite/ OS Mastermap shapefile
CartographicSymbol	Emapsite/ OS Mastermap shapefile
Harrow_vectormap_roads_Clip	Opendata/ Meridian 2 shapefile

Office for National Statistics website link is: http://www.statistics.gov.uk/hub/index.html
Opendata website link is: http://www.ordnancesurvey.co.uk/oswebsite/products/os-opendata.html
Emapsite website link is https://www.emapsite.com

All these data has been loaded into MapInfo and Model Manager for detailed analysis, both qualitative and quantitative, for suitability to be converted into a DHN and for statistical summary of the available attributes. A snapshot of the data validation process for CZ 70 using Model Manager is shown in Figure 5-1.

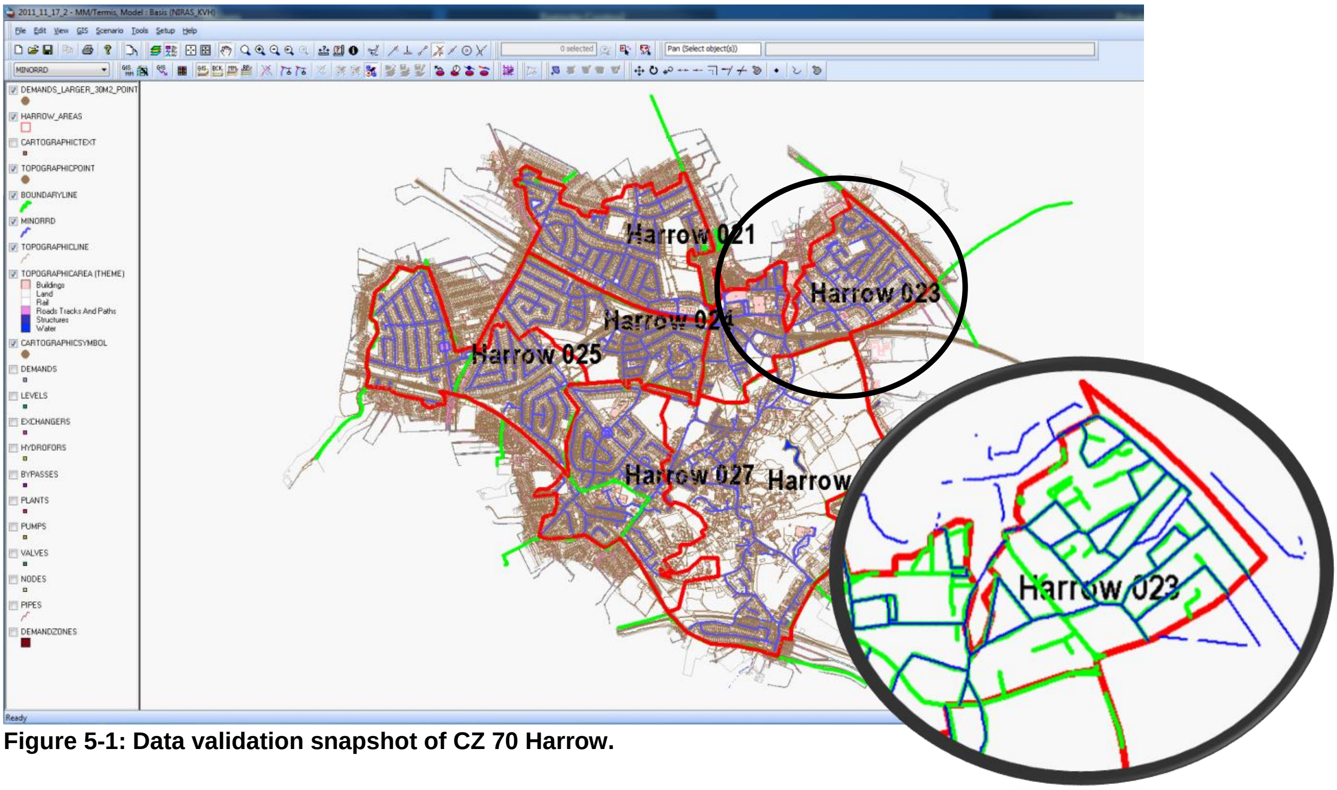


Figure 5-1: Data validation snapshot of CZ 70 Harrow.

GIS layers shown in Figure 5-1 are: Harrow_Areas, BoundaryLine, TQRoad_Clip, TopographicArea, MinorRd, TopographicLine, TopographicPoint, CartographicSymbol.

5.2 Data Adaptation

The road centre lines have been modified prior to the model build to ensure that a consistent topology is achieved for DHN modelling purposes. Road centre lines have been split on MLSOA boundaries and the relevant MLSOA name has been assigned to each pipe as an additional attribute. All centre lines outside the CZ have been deleted, unless in special cases where this would lead to isolated pipe segments along the CZ borders.

An example of the first step in road centre line to MLSOA affiliation for CZ 70 is shown in Figure 5-2.

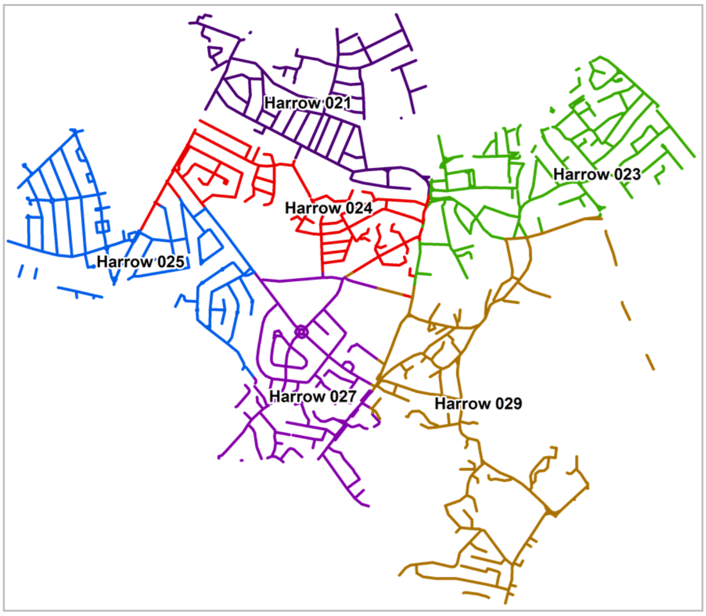


Figure 5-2: Affiliation of road centre lines to MLSOAs for CZ 70 Harrow.

GIS layers shown in Figure 5-2 is: TQRoad_Clip.

It is clear from Figure 5-2 that the isolated “pipe” segments along the MLSOA boundaries need to be manually connected to the main network topology.

The network topology has been scanned for loops and a high number of these have been removed or broken as well as doublets have been deleted. Various examples of identified loops that have been deleted or broken inside CZ 70 using Model Manager are shown in Figure 5-3.

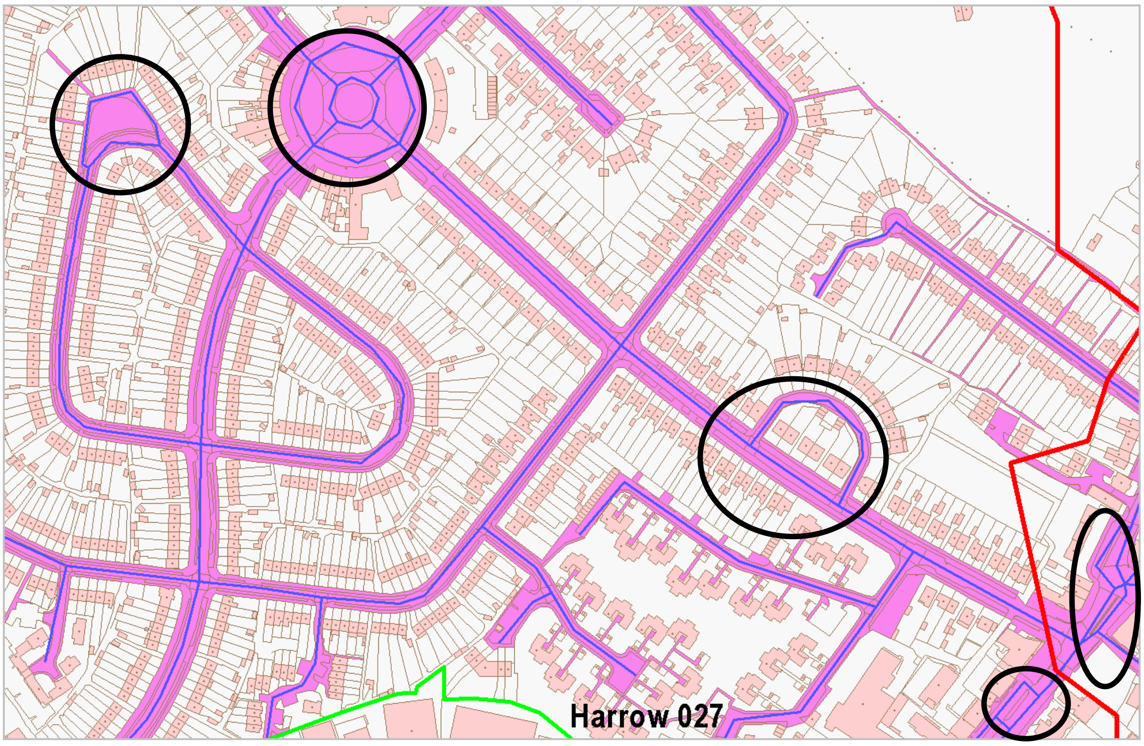


Figure 5-3: Identified and adjusted loops in CZ 70 Harrow.

GIS layers shown in Figure 5-3 are: Harrow_Areas, BoundaryLine, TQRoad_Clip, TopographicArea.

This data cleaning process is not as detailed as that needed for a final DHN design, but uses the road centre line as a basis and corrects layouts that are clearly in conflict with general DHN design principles.

Major energy transport routes, the main transmission system, have been identified; loops and excess piping in this context have been removed. An example of this in CZ 313 (Solihull) using MapInfo is shown in Figure 5-4.

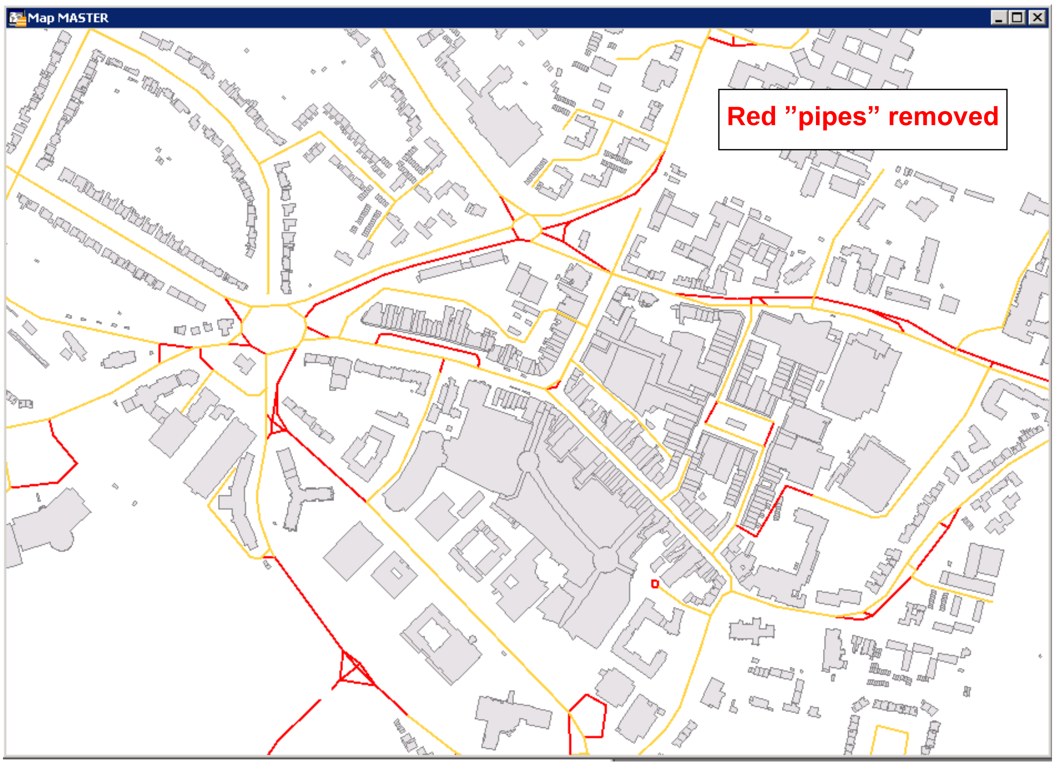


Figure 5-4: Defining the main transmission system in CZ 313 Solihull.

GIS layers shown in Figure 5-4 are: TopographicArea, Solihull_vectormap_roads_Clip.

The Buildings GIS layer (polygons) has been converted in to DH demands (points) using the building ground floor plan area as key parameter for the associated heat load. The customer points are created at the centre point of each building using a standard tool from the MapInfo program. MapInfo documentation for this procedure I provided in the text box bellow:

"Usually the center of a map object. For most map objects, the centroid is located at the middle of the object (the location halfway between the northern and southern extents and halfway between the eastern and western extents of the object). In some cases, the centroid is not at the middle point because there is a restriction that the centroid must be located on the object itself. Thus, in the case of a crescent-shaped region object, the middle point of the object may actually lie outside the limits of the region; however, the centroid is always within the limits of the region."

Buildings with a ground floor area smaller than 30 m^2 have been classified as an "Out House" and consequently assumed not to be connected to the DHN. Buildings with ground area above 200 m² have been classified as "Tertiary" and buildings in between are classified as "Dwellings".

Refer to Table 5-1. The tertiary buildings may be either commercial or institutional buildings or apartment blocks.

Area	**Classification**
[m²]	**[class]**
0 - 30	Out House
30 - 200	Dwelling
200 -	Tertiary

Table 5-1: Building classification.

The background for this assumption on building classification is documented in 12.1.2 Assumption 2 – Building Classification.

Customer energy demand is assigned to the nearest transmission pipe using the built-in demand affiliation tool in Model Manager. This will generate an extra line for each customer point pointing to the nearest point in the nearest model pipe; from here the demand is routed to the nearest node where it is assigned. The affiliation lines can therefore be used as an approximated basis for distribution pipes.

An example of this process for CZ 70 Harrow is shown in Figure 5-5.

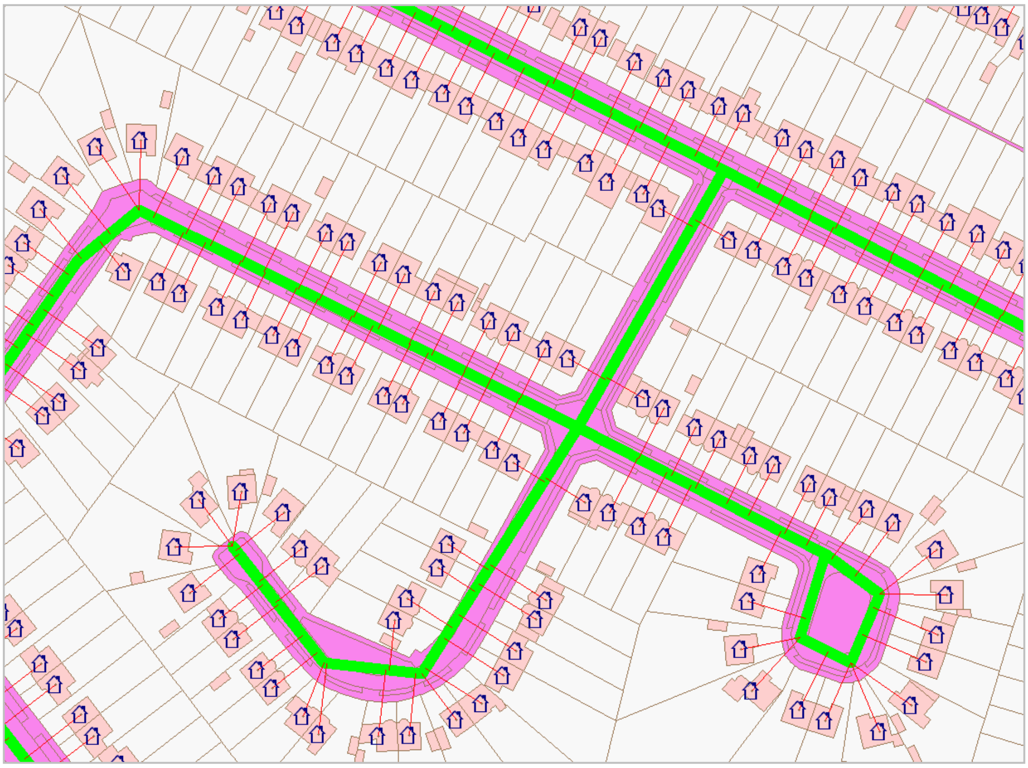


Figure 5-5: Buildings converted to customers and affiliated to model pipes.

6 MODEL BUILD & CONFIGURATION

After having completed the data preparation stage the modified GIS data for each sample CZ were converted into a unified DHN model covering the transmission pipes. The distribution pipes as generated from the demand affiliation were exported for separate statistical analysis.

6.1 Model Build

CZ 148 Westminster converted to a hydraulic network model in TERMIS is shown in Figure 6-1.

Figure 6-1: TERMIS model of CZ 148 Westminster.

Additional corrections to pipeline data were performed after the model generation. These corrections mainly consisted of further deletion of pipes for hydraulic/thermodynamic network efficiency purposes.

All pipes have been classified by road type to be able to distinguish re-instatement cost by road type. An example of the road type classification process is shown for CZ 70 Harrow in Figure 6-2.

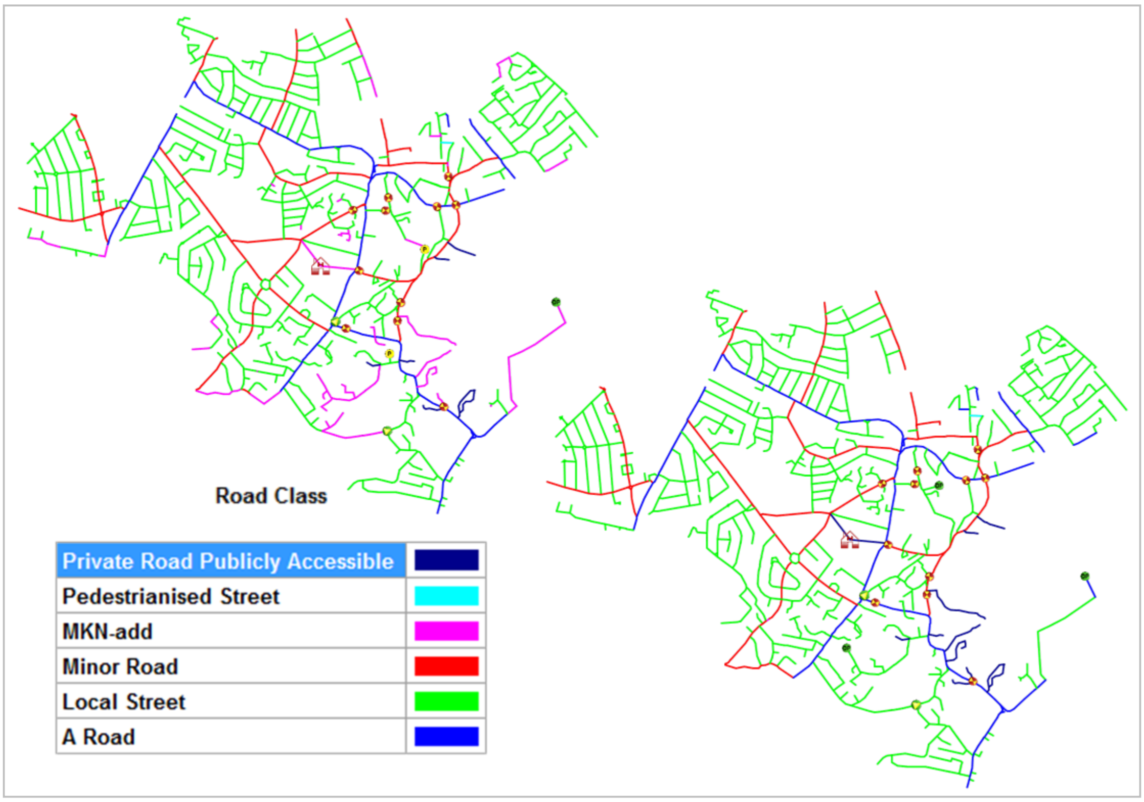


Figure 6-2: Road type classification of CZ 70 Harrow.

During the classification, the road class is transferred to the pipe generated from the road centre line and manually added pipes are first classified as “MKN-add” and when all pipes are classified, the manually added pipes are re-classified to fit the general road classification. This is illustrated in Figure 6-2 by the left and right version of the road classification.

For operational efficiency purposes pressure zones have been identified and hydraulically separated by closed valves and booster pumps at the connecting points. In some cases additional valves have been added to close hydraulically critical loops.

Pressure zones were identified using 3D topology plots of the ground elevations at model nodes. This is shown for CZ 70 Harrow in Figure 6-3.

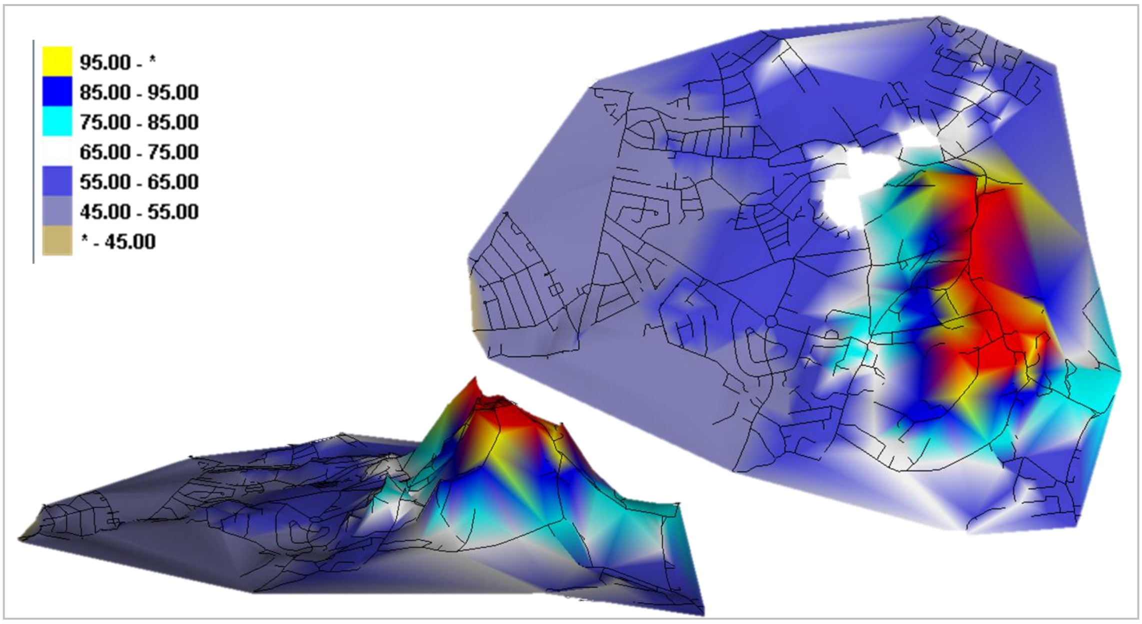


Figure 6-3: 3D plot of ground elevation for CZ 70 Harrow.

The separation of the high elevation area by closed valves and boosters for CZ 70 is illustrated in Figure 6-4.

Figure 6-4: Separation of two pressure zones in CZ 70 Harrow.

Separation of a high elevated area in CZ 313 is illustrated in Figure 6-5 which also includes several closed valves added to close critical loops that hinder localisation of the main transmission system.

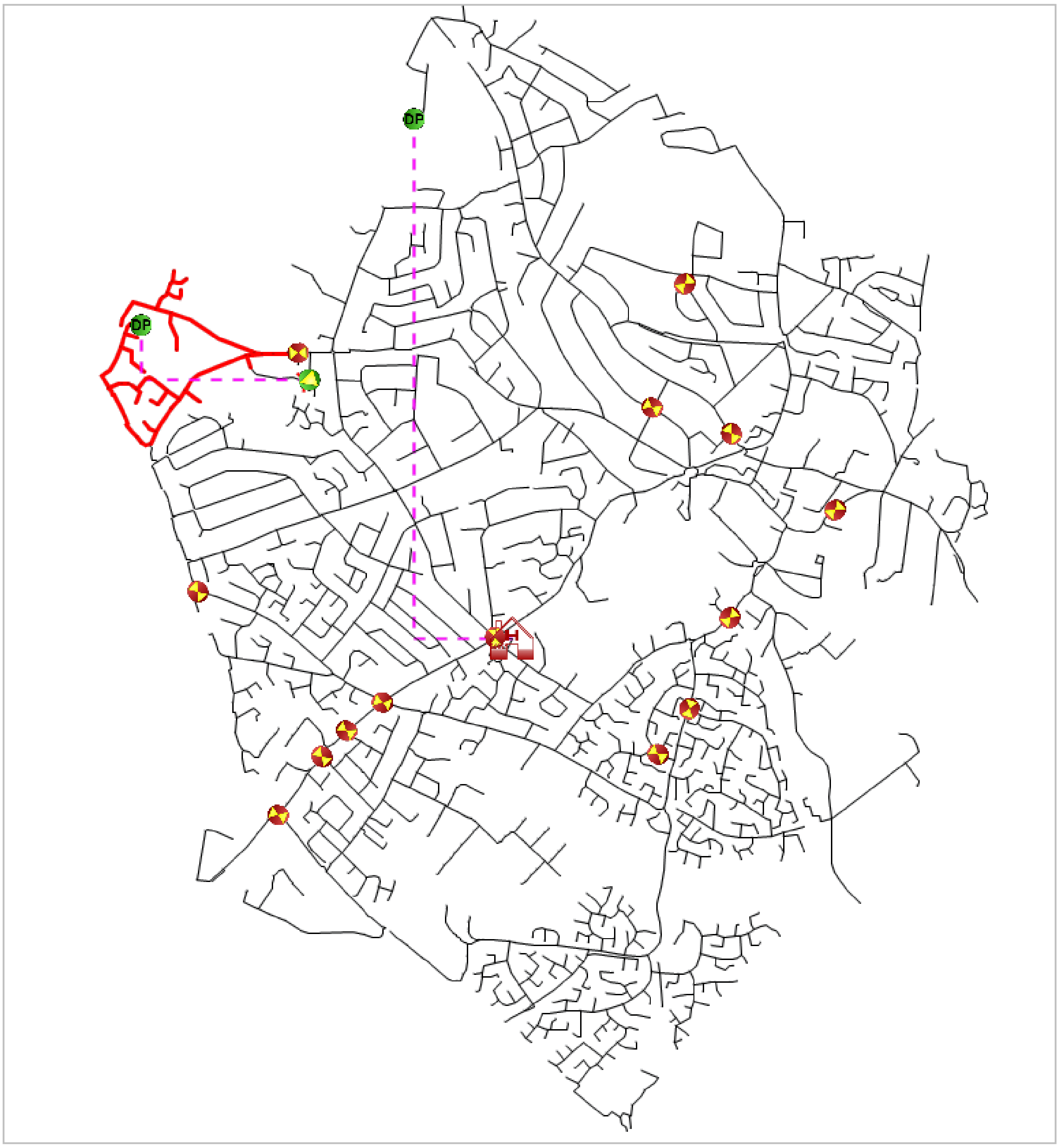


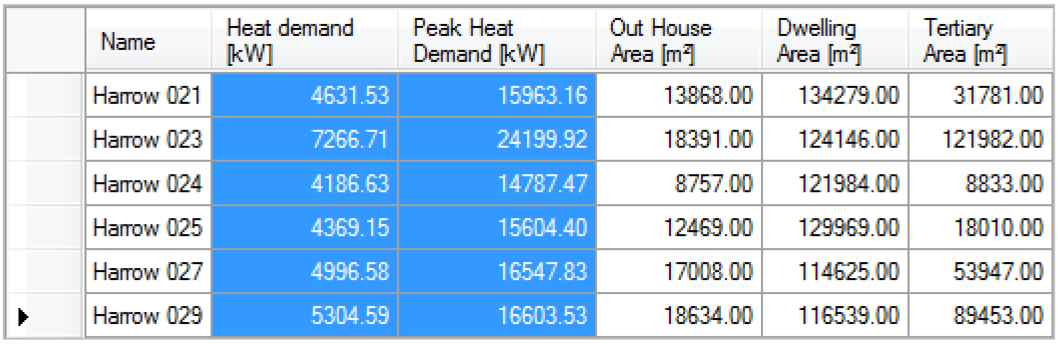
Figure 6-5: Separation of high elevated area and closing of critical loops for CZ 313 Solihull.

6.2 Heat Loads

To define and run basic scenarios, for dimensioning and average conditions, both average heat demands and peak heat demands are required in the models, as hourly values. These are added to the models via LOOKUP tables which allow each scenario in the model to easily shift between the various heat loads from the LOOKUP table.

The same LOOKUP table also contains information on accumulated building area of each building class which is used to automatically distribute the chosen load onto the buildings by the building area ratio.

The LOOKUP table in TERMIS for CZ 70 is shown in Table 6-1.



Name	Heat demand [kW]	Peak Heat Demand [kW]	Out House Area [m²]	Dwelling Area [m²]	Tertiary Area [m²]
Harrow 021	4631.53	15963.16	13868.00	134279.00	31781.00
Harrow 023	7266.71	24199.92	18391.00	124146.00	121982.00
Harrow 024	4186.63	14787.47	8757.00	121984.00	8833.00
Harrow 025	4369.15	15604.40	12469.00	129969.00	18010.00
Harrow 027	4996.58	16547.83	17008.00	114625.00	53947.00
Harrow 029	5304.59	16603.53	18634.00	116539.00	89453.00

Table 6-1: Heat load LOOKUP table for the TERMIS model of CZ 70 Harrow.

The heat loads in Table 6-1 are taken from Table 4-1 and the total building areas are exported from the model configuration data in Model Manager, which again is originating from the GIS building layer. The building distribution into categories is described in section 5.2 and specified in 12.1.2, Assumption 2 – Building Classification.
Accordingly similar tables have been generated for CZ 148 Westminster and CZ 313 Solihull using heat load data from Table 4-2 - Table 4-3.

The actual heat demand at each customer point classified as Dwelling or Tertiary within each MLSOA (E_j) has been configured in the model to be calculated as:

$$E_j = \frac{A_i}{\sum A_{Dwellings} + \sum A_{Tertiary}} \cdot E_{TY}$$

Equation 6-1

Where:

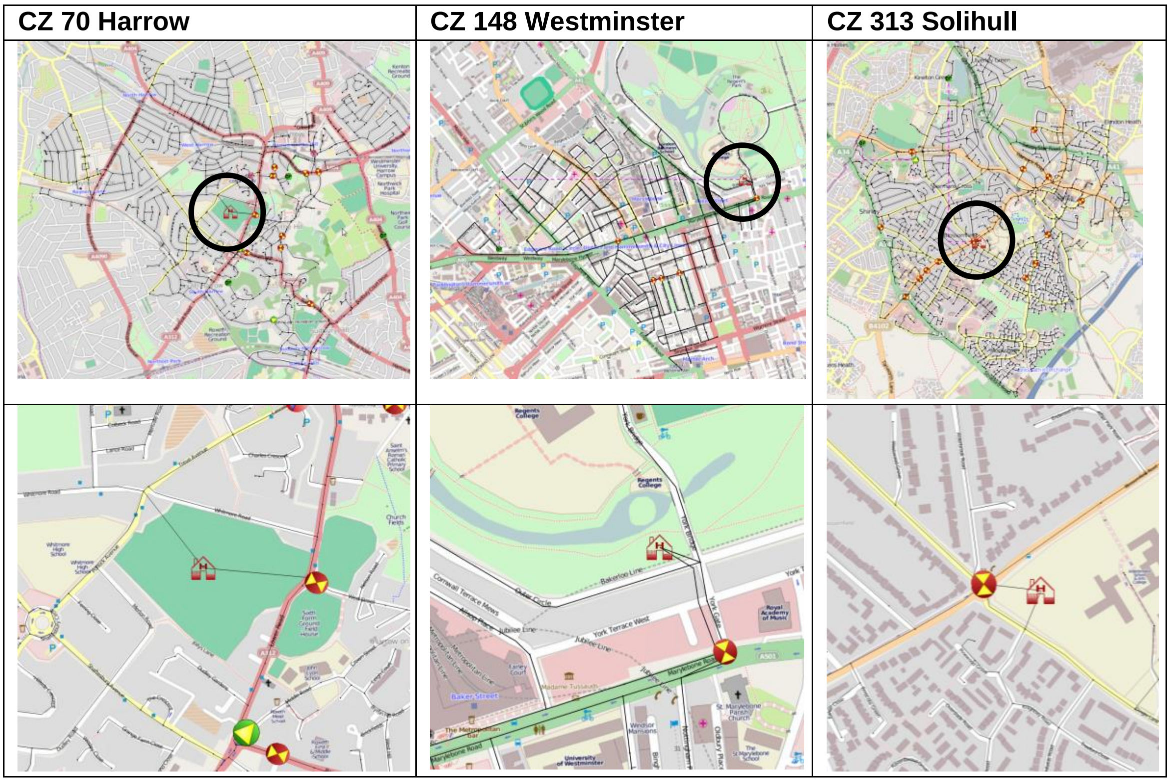
$E_{i,j}$	Heat demand for heat type j at building i
A_i	Area of building i
$A_{Dwellings}$	Area of all Dwellings within the MLSOA
$A_{Tertiary}$	Area of all Tertiary within the MLSOA
E_{TY}	Total heat load of the MLSOA
i	Index for each building of classes Dwellings and Tertiary
j	Index for selected heat load (average heat demand or peak heat demand)

This approach is an approximation which is widely used for modelling on similar data grounds. It is limited due to the lack information for the number of floors in a building; the GIS data only enables the identification of building as a two dimensional polygon. For the MLSOAs in question the impact is expected to be small as most areas have buildings of similar height.

6.3 Operational Configuration

When positioning the DHP in the model various conditions were considered:

a. Available space, typically a park or similar.
b. Geographical placement typically central to the network.
c. Adequate transportation roads to the plant.
d. Topographically central with respect to elevation.


CZ 70 Harrow

CZ 148 Westminster

CZ 313 Solihull

Figure 6-6: Positioning of the district heating plants within the 3 CZ models.

For a real design, the DHP would most likely be located outside of the residential areas and supplying the MLSOA via a bigger transmission pipeline and sub-stations (heat exchangers) at the MLSOAs supply points.

Each DHP has been configured to operate with operational controls and settings as listed in Table 6-2.

Control	Setting	Comment
Plant supply temperature	90 °C	
Plant return temperature	50 °C	
Plant return pressure	1.5 bar	
Plant controlling difference pressure	0.5/0.7 bar	At critical consumer
Return temperature adaption	ON	

Table 6-2: DHP Controls and settings.

Other required and relevant DHN controls and settings have been defined as listed in Table 6-3.

Control	Setting	Comment
Ambient ground temperature	10 °C	
Cooling at consumers	45 °C	
Booster difference pressure	0.5 bar	At critical location

Table 6-3: DHN Controls and settings.

Enabling return temperature adaption in TERMIS converts the cooling at the consumers to a return temperature, which is then adapted to meet the return temperature at the plant. This way, both mass and energy balance is obtained in the model without having to adjust all customer cooling values manually.

Positioning and pressure difference control of the DHP illustrated in Figure 6-7 for CZ 148 Westminster.

Figure 6-7: DHP position and control for CZ 148 Westminster.

7 SCENARIOS & SIMULATIONS

With the models built by topology, heat loads assigned and operational controls and settings defined the system is now ready for further defining and running the required scenarios.

7.1 Pipeline Dimensioning& Costs

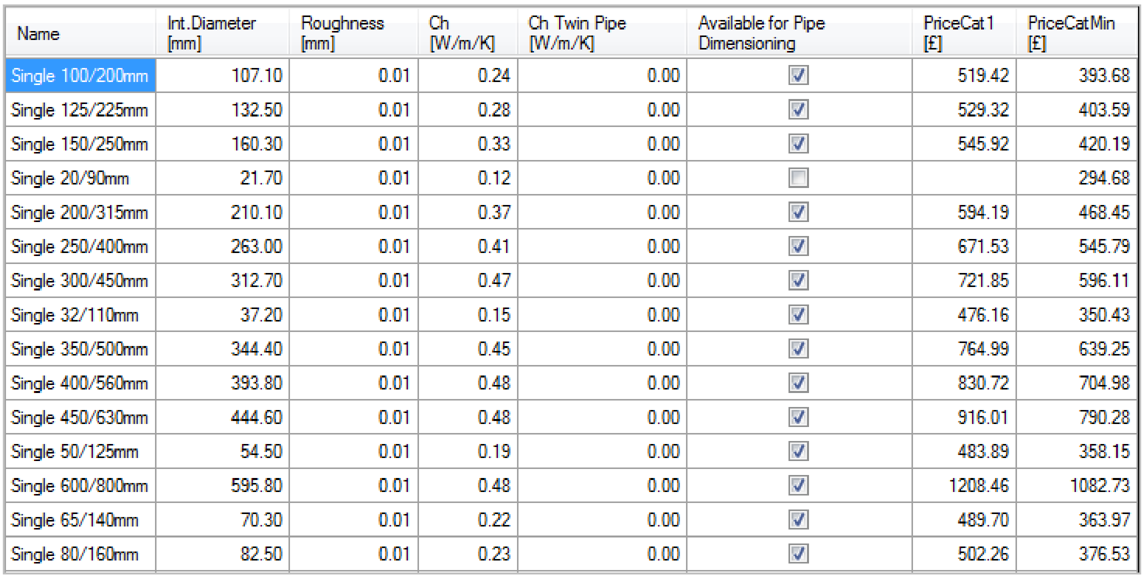
The pipeline dimensioning scenarios have been run as the first, as these define the pipe types which are to be known before any other scenario can be run.

Global pipeline dimensioning criteria have been defined for the main transport pipes, defined as pipes with diameter from 200 mm and above and for the secondary transmission pipes defined as pipes with diameter below 200 mm. These dimensioning criteria are listed in Table 7-1

Index	Pipe Category	Velocity Criteria	Head Loss Criteria
1	D ≥ 200 mm	v ≤ 2.0 m/s	ΔH ≤ 10mwc/km
2	D < 200 mm	v ≤ 1.5 m/s	ΔH ≤ 10 mwc/km

Table 7-1: Pipeline dimensioning criteria.

A pipe type catalogue and cost books for pipe types and HIUs have been established from Ref. 1, see Table 7-2 . The cost columns, the two rightmost columns, are used for cost calculations of the DHN where the PriceCat1 column is used for major roads (Primary roads and A roads) with high reinstatement costs and the PriceCatMin is used for minor roads with lower reinstatement costs.



Name	Int.Diameter [mm]	Roughness [mm]	Ch [W/m/K]	Ch Twin Pipe [W/m/K]	Available for Pipe Dimensioning	PriceCat1 [£]	PriceCatMin [£]
Single 100/200mm	107.10	0.01	0.24	0.00	☑	519.42	393.68
Single 125/225mm	132.50	0.01	0.28	0.00	☑	529.32	403.59
Single 150/250mm	160.30	0.01	0.33	0.00	☑	545.92	420.19
Single 20/90mm	21.70	0.01	0.12	0.00	☐		294.68
Single 200/315mm	210.10	0.01	0.37	0.00	☑	594.19	468.45
Single 250/400mm	263.00	0.01	0.41	0.00	☑	671.53	545.79
Single 300/450mm	312.70	0.01	0.47	0.00	☑	721.85	596.11
Single 32/110mm	37.20	0.01	0.15	0.00	☑	476.16	350.43
Single 350/500mm	344.40	0.01	0.45	0.00	☑	764.99	639.25
Single 400/560mm	393.80	0.01	0.48	0.00	☑	830.72	704.98
Single 450/630mm	444.60	0.01	0.48	0.00	☑	916.01	790.28
Single 50/125mm	54.50	0.01	0.19	0.00	☑	483.89	358.15
Single 600/800mm	595.80	0.01	0.48	0.00	☑	1208.46	1082.73
Single 65/140mm	70.30	0.01	0.22	0.00	☑	489.70	363.97
Single 80/160mm	82.50	0.01	0.23	0.00	☑	502.26	376.53

Table 7-2: Pipe type catalogue and cost book.

Note that the 20 mm pipe is not to be used for dimensioning of the transmission system; this pipe type is only included in the pipe catalogue table for cost calculations.

Description	HIU	Installation	Total per unit (£)
Domestic HIU (Apartment) retrofit including ancillary works	£700	£900	£1,600*
Domestic HIU (House) retrofit including ancillary works	£850	£900	£1,750
Commercial heat exchanger including ancillary works	£3000	£1800	£4,800

Table 7-3: HIU cost book from Ref. 1.

Using the above pipeline dimensioning criteria and associated pipe type catalogue the resulting DHN is dimensioned in two steps:

1. Conduct a simulation using criteria set 1 from Table 7-1 with all pipes set to “Unknown” type.
2. Apply the selected pipe types to all pipes with diameter of 200 mm and above, leave the remaining pipes with “Unknown” type.
3. Conduct a second simulation using criteria set 2 from Table 7-1.
4. Apply the selected pipe types to all pipes with type “Unknown”.

After having completed the four steps above for each CZ model a pipe type is assigned to all pipes within the DHN. The result of such a dimensioning procedure is shown for CZ 148 Westminster in Figure 7-1.

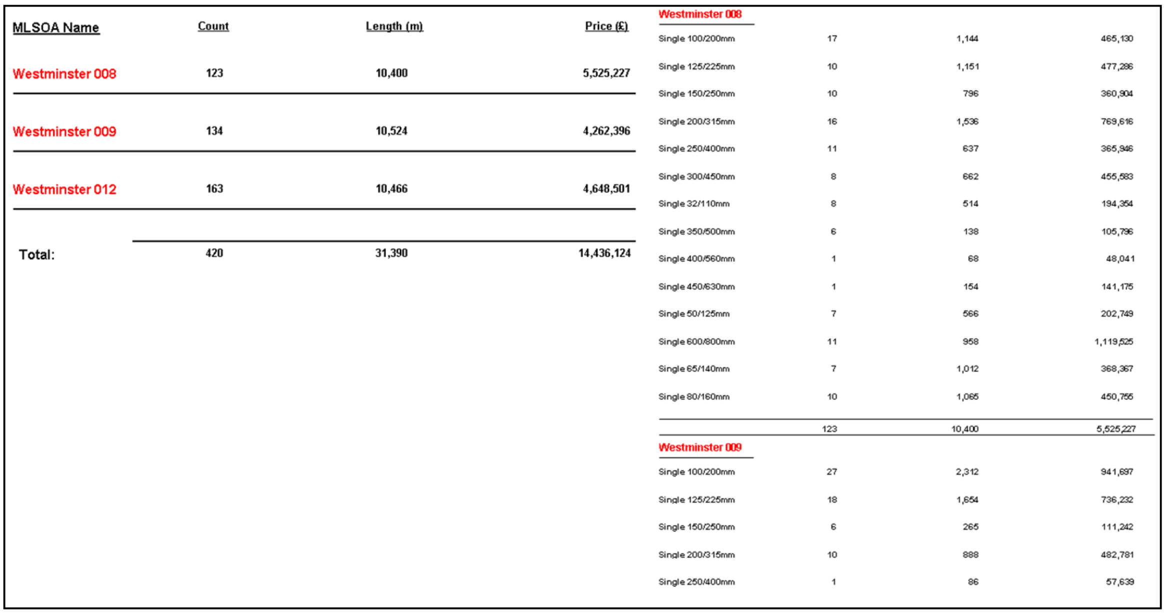
Figure 7-1: Completed pipeline dimensioning for CZ 148 Westminster.

With the pipeline dimensioning complete for each CZ the associated costs of the complete DHN has been extracted via a dedicated report which combines the selected pipe type, the pipe length and the road type, see Figure 6-2, extracts the correct price from the cost book, Table 7-2 and calculates the total cost for each pipe.

Two cost reports have been defined, a summary report and a detailed report, which shows several levels of information on the calculated DHN costs.

- The Summary report.
  Total DHN cost and cumulated pipeline length per MLSOA.
- The Detailed report.
  Total cost per pipe and cumulated pipeline length per pipe type per MLSOA.

The Summary report for CZ 148 Westminster is shown to the left in Figure 7-2, and a selection of the Detailed report is shown to the right.



MLSOA Name	Count	Length (m)	Price (£)
Westminster 008	123	10,400	5,525,227
Westminster 009	134	10,524	4,262,396
Westminster 012	163	10,466	4,648,501
Total:	420	31,390	14,436,124

Westminster 008			
Single 100/200mm	17	1,144	465,130
Single 125/225mm	10	1,151	477,286
Single 150/250mm	10	796	360,904
Single 200/315mm	16	1,536	769,616
Single 250/400mm	11	637	365,946
Single 300/450mm	8	662	455,583
Single 32/110mm	8	514	194,354
Single 350/500mm	6	138	105,796
Single 400/560mm	1	68	48,041
Single 450/630mm	1	154	141,175
Single 50/125mm	7	566	202,749
Single 600/800mm	11	958	1,119,525
Single 65/140mm	7	1,012	368,367
Single 80/160mm	10	1,065	450,755
	123	10,400	5,525,227
Westminster 009			
Single 100/200mm	27	2,312	941,697
Single 125/225mm	18	1,654	736,232
Single 150/250mm	6	265	111,242
Single 200/315mm	10	888	482,781
Single 250/400mm	1	86	57,639

Figure 7-2: Pipe cost report for CZ 148 Westminster.

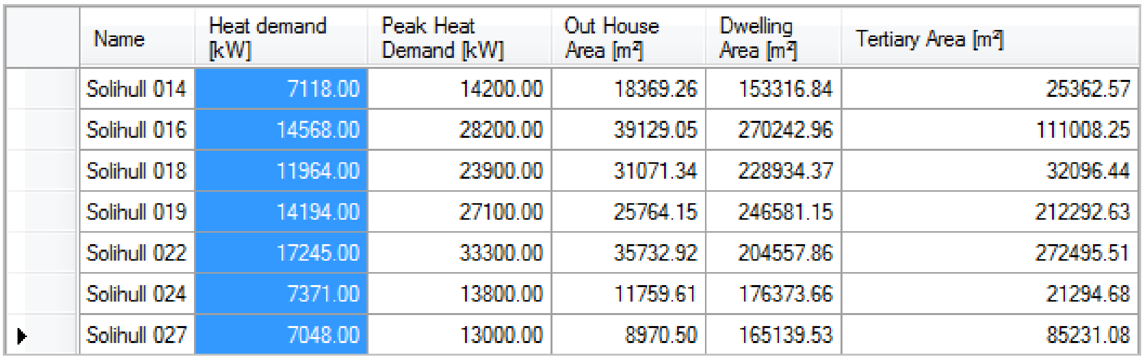
The complete cost reports for all three MLSOA can be found in 12.2Appendix 2 – Cost Reports.

7.2 Heat Loss& Pumping Energy

To calculate the expected annual heat loss and the required pumping energy from the DHN transmission system it is required to include both seasonal and daily variation in heat demand.

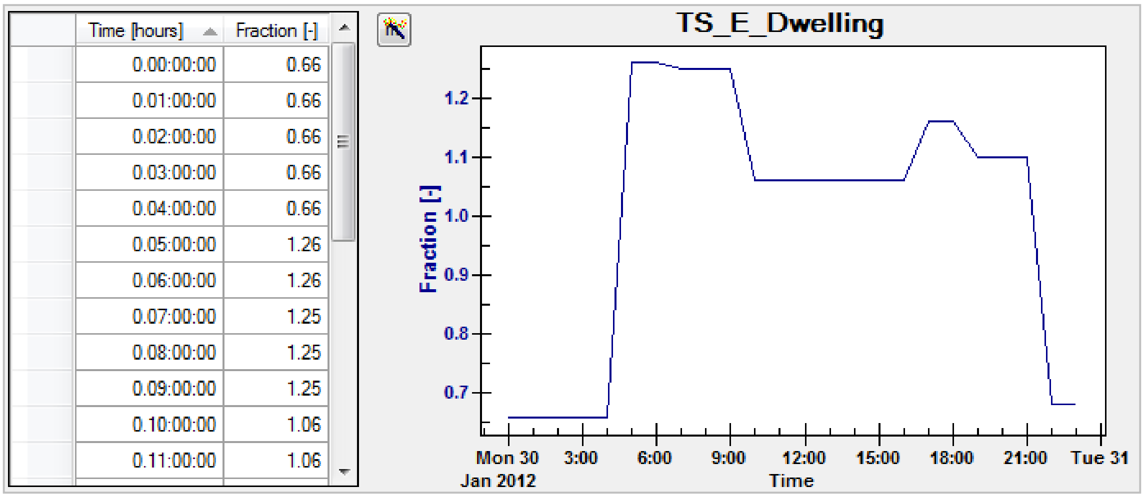
Dedicated scenarios have been configured for each season, summer, winter and transition and diurnal demand curves have been added for working days and weekend days. This leads to 6 scenarios for each CZ to be run to generate results for each season for each day type. In total 18 scenarios.

These scenarios have been configured by use of the demand data originating from EDF-Eifer's Work Package 2 outputs, see 12.3 Appendix 3 – Heat Demands. These data have been scaled on MLSOA level and entered into the model as a daily average for each season combined with an hourly diurnal normalized curve describing the variation over the day, see Table 7-4 and Figure 7-3.



Name	Heat demand [kW]	Peak Heat Demand [kW]	Out House Area [m²]	Dwelling Area [m²]	Tertiary Area [m²]
Solihull 014	7118.00	14200.00	18369.26	153316.84	25362.57
Solihull 016	14568.00	28200.00	39129.05	270242.96	111008.25
Solihull 018	11964.00	23900.00	31071.34	228934.37	32096.44
Solihull 019	14194.00	27100.00	25764.15	246581.15	212292.63
Solihull 022	17245.00	33300.00	35732.92	204557.86	272495.51
Solihull 024	7371.00	13800.00	11759.61	176373.66	21294.68
Solihull 027	7048.00	13000.00	8970.50	165139.53	85231.08

Table 7-4: Heat demands for CZ 313 Solihull, Winter Weekday.



Time [hours]	Fraction [-]
0.00:00:00	0.66
0.01:00:00	0.66
0.02:00:00	0.66
0.03:00:00	0.66
0.04:00:00	0.66
0.05:00:00	1.26
0.06:00:00	1.26
0.07:00:00	1.25
0.08:00:00	1.25
0.09:00:00	1.25
0.10:00:00	1.06
0.11:00:00	1.06

Figure 7-3: Normalized diurnal variation curve CZ 313 Solihull, Winter Weekday.

The same diurnal variation has been applied for both dwellings and tertiary.

Each scenario is run for a 24 hour period and results for heat loss and pumping power requirement extracted and scaled by the number of days the specific scenario represent within a year, refer to Table 7-5.

	Winter	**Summer**	**Transition**	**Total**
Weekday	87	88	86	**261**
Weekend	34	34	36	**104**
Total	**121**	**122**	**122**	**365**

Table 7-5: Distribution of days by seasons.

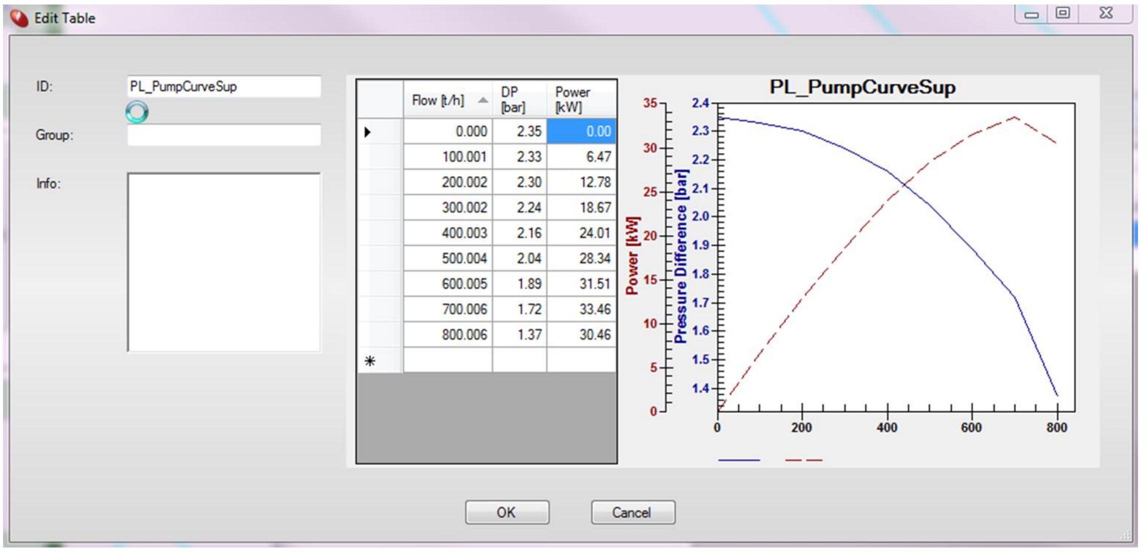
Daily heat losses are extracted from each scenario for each MLSOA and the total annual heat loss is calculated as:

$$\Delta E^{MLSOA} = \sum \Delta E_{i,j}^{MLSOA} \cdot N_{i,j} \qquad \text{Equation 7-1}$$

Where:

ΔE^{MLSOA}	Annual heat loss for a MLSOA
$\Delta E_{i,j}$	Daily heat loss for season type i and day type j
$N_{i,j}$	Number of days of season type i and day type j

For calculation of the pumping power requirement, i.e. the power to be delivered from the pumps without including efficiency of pump and motor etc. a characteristic pumping curve is required. A standard pump has been selected for all three models and the power curve been adjusted to exclude influence from efficiencies, i.e. the pump is assumed to operate at 100% efficiency at all operational situations. See Figure 7-4.



ID: PL_PumpCurveSup

Group:

Info:

Flow [t/h]	DP [bar]	Power [kW]
0.000	2.35	0.00
100.001	2.33	6.47
200.002	2.30	12.78
300.002	2.24	18.67
400.003	2.16	24.01
500.004	2.04	28.34
600.005	1.89	31.51
700.006	1.72	33.46
800.006	1.37	30.46

Figure 7-4: Pump characteristic used for calculation of pump power requirements.

Daily pumping power requirements are extracted from each scenario and the total annual pumping power requirement is calculated on CZ level as:

$$E^{CZ} = \sum \Delta E_{i,j}^{CZ} \cdot N_{i,j} \qquad \text{Equation 7-2}$$

Where:

E^{CZ}	Annual pumping power requirements for a CZ
$E_{i,j}$	Daily pumping power requirements for season type i and day type j
$N_{i,j}$	Number of days of season type i and day type j

8 ANALYSIS OF RESULTS

All results generated from the data preparations, model building and scenario simulations are compiled and analysed in the following sections 8.1 - 8.5.

In general, it is assumed that relations exists between LOD, LOT, COT, Heat Loss and Pump Power Requirement on one side and either ETI Road Length, Area Heat Density (AHD), Line Heat Density (LHD) or Line Peak Heat Density (LPHD) on the other side.

An (AHD, LHD) plot has been made for all MLSOAs based on Table 4-1 - Table 4-3 to investigate if a clear correlation exist between these two. This plot is seen in Figure 8-1.

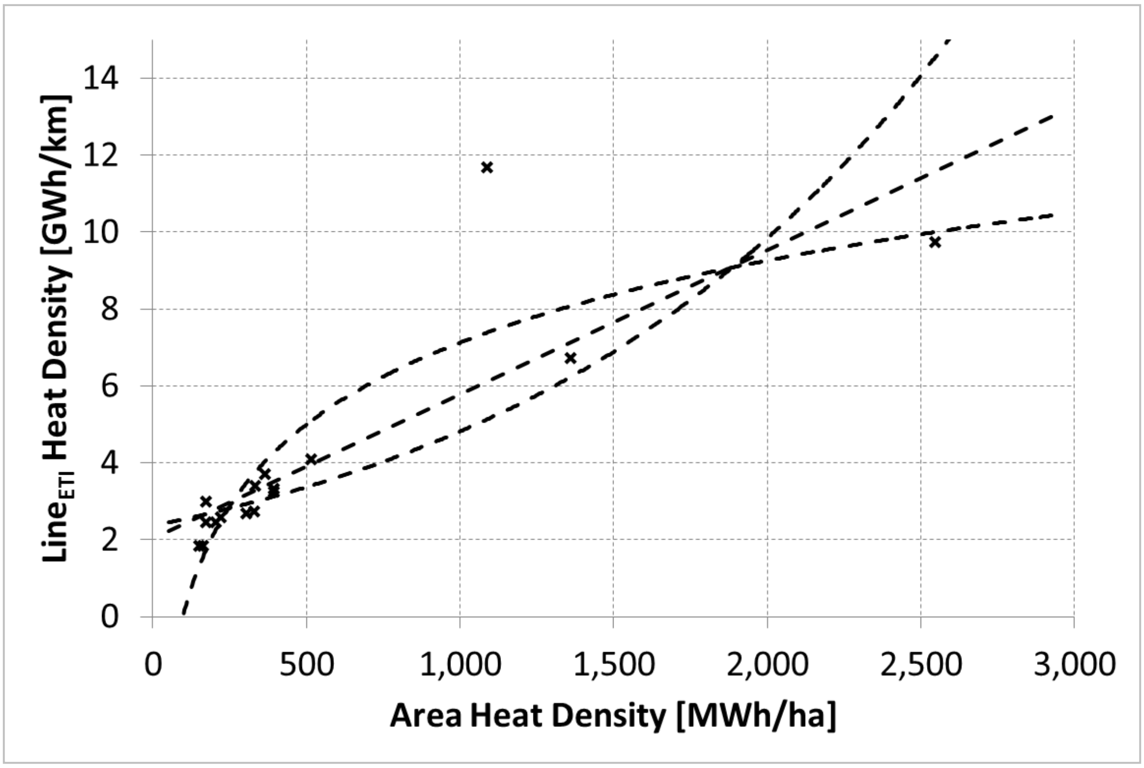


Figure 8-1: AHD- LHD correlation.

Since a linear relation through (0, 0) can be rejected from a visual inspection there will be differences between investigating an AHD-relation or LHD relation for the parameters listed above and both relations need to be investigated in each case.

The values of AHD and LHD used in the analyses are the values as derived in Table 4-1 - Table 4-3. Specifically this means that the value of LHD is defined as Line Heat Density by road length as given from the ETI data, not pipe length as given from the model, which is indicated in some of the plots by using ETI as denominator, LHD$_{ETI}$.

8.1 LOD Analysis

The overall results on the creation of distribution pipes during data preparations and model build are collated into this LOD analysis. The distribution pipes are not part of the modelled DHNs so the distribution pipe results and observations are analysed for statistical purposes only to provide the distribution pipe length, LOD.

LOD is qualitatively likely to be related to building density by area, which again is likely to be related to Area Heat Density. It is therefore assumed that the (AHD, LOD) relation is more significant than the (LHD, LOD) relation.

The key results for LOD given as totals and average values per connection within each CZ and MLSOA are available in Table 8-1.

	Output								
MLSOA	**Connection Points Total**	**Connection Points Dwelling**	**Connection Points Tertiary**	**Distribution Pipe Length Total**	**Distribution Pipe Length Dwelling**	**Distribution Pipe Length Tertiary**	**LOD^{TOT} (Total)**	**LOD^{D} (Dwelling)**	**LOD^{T} (Tertiary)**
[Name]	**[#]**	**[#]**	**[#]**	**[km]**	**[km]**	**[km]**	**[m/c]**	**[m/c]**	**[m/c]**
Harrow 021	**2,157**	**2,103**	**54**	**38.17**	**36.71**	**1.46**	**17.70**	**17.47**	**26.99**
Harrow 023	**1,921**	**1,730**	**191**	**39.65**	**33.88**	**5.83**	**20.65**	**19.58**	**30.50**
Harrow 024	**2,121**	**2,105**	**16**	**36.27**	**35.82**	**0.47**	**17.11**	**17.01**	**29.47**
Harrow 025	**2,103**	**2,076**	**27**	**38.48**	**37.72**	**0.94**	**18.32**	**18.17**	**34.73**
Harrow 027	**2,037**	**1,954**	**83**	**39.64**	**36.85**	**2.60**	**19.46**	**18.87**	**31.26**
Harrow 029	**1,789**	**1,610**	**179**	**39.34**	**33.69**	**5.81**	**22.06**	**20.95**	**32.44**
Total Zone	**12,128**	**11,578**	**550**	**231.76**	**214.66**	**17.09**	**19.11**	**18.55**	**31.08**

Table 8-1: LOD results for CZ 70 Harrow.

	Output								
MLSOA	**Connection Points Total**	**Connection Points Dwelling**	**Connection Points Tertiary**	**Distribution Pipe Length Total**	**Distribution Pipe Length Dwelling**	**Distribution Pipe Length Tertiary**	**LOD^{TOT} (Total)**	**LOD^{D} (Dwelling)**	**LOD^{T} (Tertiary)**
[Name]	**[#]**	**[#]**	**[#]**	**[km]**	**[km]**	**[km]**	**[m/c]**	**[m/c]**	**[m/c]**
Westminster 008	**971**	**766**	**205**	**26.8**	**20.86**	**5.86**	**27.52**	**27.23**	**28.59**
Westminster 009	**928**	**724**	**204**	**17.3**	**12.32**	**4.94**	**18.60**	**17.02**	**24.22**
Westminster 012	**1,409**	**1,192**	**217**	**28.1**	**23.38**	**4.69**	**19.92**	**19.61**	**21.61**
Total Zone	**3,308**	**2,682**	**626**	**72.2**	**56.56**	**15.49**	**21.78**	**21.09**	**24.74**

Table 8-2: LOD results for CZ 148Westminster.

	Output								
MLSOA	Connection Points Total	Connection Points Dwelling	Connection Points Tertiary	Distribution Pipe Length Total	Distribution Pipe Length Dwelling	Distribution Pipe Length Tertiary	LOD$_{TOT}$ (Total)	LOD$_{D}$ (Dwelling)	LOD$_{T}$ (Tertiary)
[Name]	[#]	[#]	[#]	[km]	[km]	[km]	[m/c]	[m/c]	[m/c]
Solihull 014	2,086	2,040	46	50.77	48.14	2.62	24.34	23.60	56.96
Solihull 016	3,768	3,606	162	92.39	84.07	8.32	24.52	23.31	51.36
Solihull 018	3,735	3,682	53	76.32	74.71	1.61	20.43	20.29	30.38
Solihull 019	2,811	2,565	246	72.76	63.58	9.18	25.88	24.79	37.32
Solihull 022	3,435	3,255	180	80.25	71.17	8.95	23.35	21.86	49.72
Solihull 024	2,523	2,474	49	53.84	51.98	1.86	21.34	21.01	37.96
Solihull 027	2,352	2,284	68	51.71	48.32	3.39	21.99	21.16	49.85
Total Zone	20,710	19,906	804	478.00	441.97	35.93	23.08	22.20	44.69

Table 8-3: LOD results for CZ 313Solihull.

An LOD analysis is then conducted by following two different approaches: one assuming all buildings having a heat demand is connected to the DHN, and another approach setting a maximum limit for LOD assuming that buildings having a heat demand that are located further away from the DHN than the maximum limit will not be connected.

8.1.1 LOD Approach I - All Consumers are Connected

The LOD data are plotted in Figure 8-2 - Figure 8-3, where linear relations have been applied as shown in the plots and the Standard Error of Mean (SEM) calculated to select the best relation.

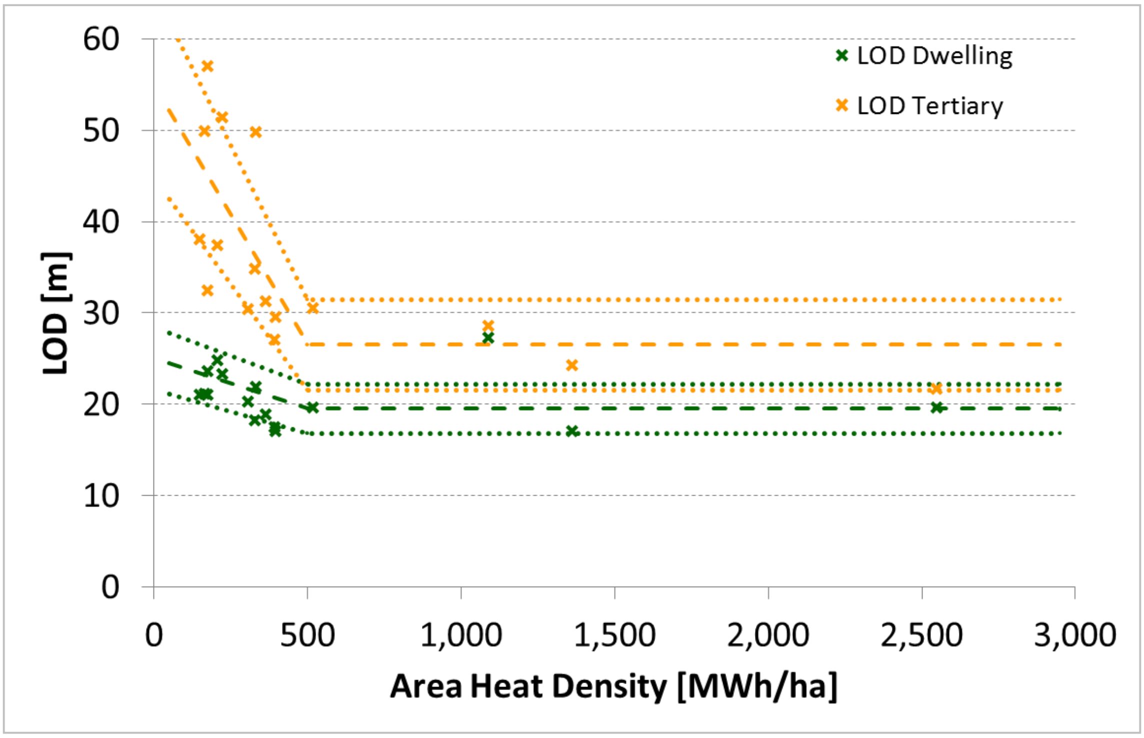


Figure 8-2: (AHD, LOD) plot.

Tertiary: SEM = ± 19 %, Dwellings: ± 14 %.

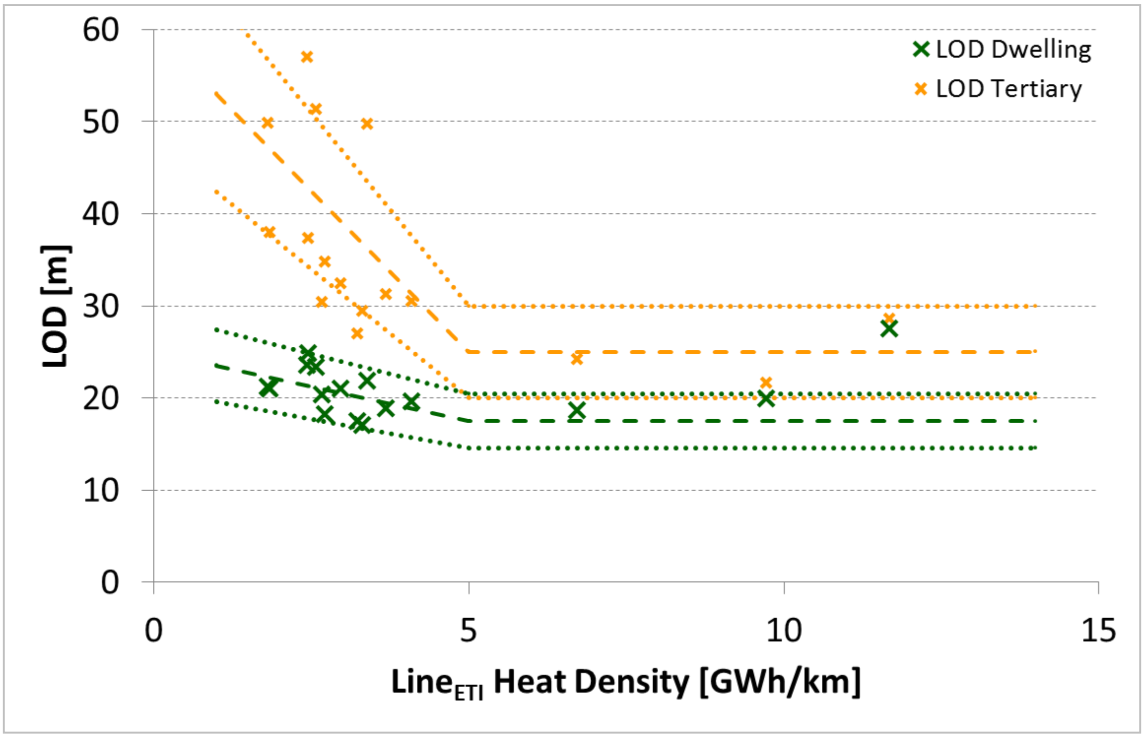


Figure 8-3: (LHD, LOD) plot.

Tertiary: SEM = ± 20 %, Dwellings: ± 17 %.

This assumption that LOD is related to AHD is quantitatively underlined by the SEM being smallest for the (AHD, LOD) relation.

This relation is therefore concluded to be adequate and well documented as a result for further use by the various cost algorithms.

(AHD, LOD) Relation for Dwellings:

AHD < 500 MWh/ha $$LOD_D(AHD) = 25m - 0.011m \cdot \frac{ha}{MWh} \cdot AHD$$ Equation 8-1

AHD ≥ 500 MWh/ha $$LOD_D = 19.5m$$

Where a value of SEM = ± 14 % can be applied for sensitivity analysis.

(AHD, LOD) Relation for Tertiary:

AHD < 500 MWh/ha $$LOD_T(AHD) = 55m - 0.057m \cdot \frac{ha}{MWh} \cdot AHD$$ Equation 8-2

AHD ≥ 500 MWh/ha $$LOD_T = 26.5m$$

Where a value of SEM = ± 19 % can be applied for sensitivity analysis.

AHD to be entered in MWh/ha for both Equation 8-1 and Equation 8-2.

8.1.2 Approach II - Applying an LOD Upper Limit

A deeper study would be able to determine an economically feasible upper limit for LOD based on a requirement of the payback time for connecting a building to the DHN must be less than a specified number of years. Such an analysis is outside the scope of the current study, but an assessment of the consequences on LOD has been made assuming that the upper limits for LOD$_D$ and LOD$_T$ are set at 40 m and 80 m respectively.

The results for LOD frequency analysis for each CZ are shown in Figure 8-4 - Figure 8-6. In the textboxes to the left of the graphs is the percentage of Distribution pipes within the set upper limits for LOD$_D$ and LOD$_T$ on MLSOA basis presented as well as the average LOD.

Dwellings		
MLSOA	F	LOD$_D$
Harrow 021	99%	17.05
Harrow 023	95%	17.18
Harrow 024	99%	16.83
Harrow 025	99%	18.17
Harrow 027	98%	18.10
Harrow 029	92%	16.51
Average	**97%**	**17.31**

Tertiary		
MLSOA	F	LOD$_T$
Harrow 021	100%	27.21
Harrow 023	97%	28.76
Harrow 024	94%	25.13
Harrow 025	92%	26.77
Harrow 027	98%	29.69
Harrow 029	94%	26.98
Average	**96%**	**27.42**

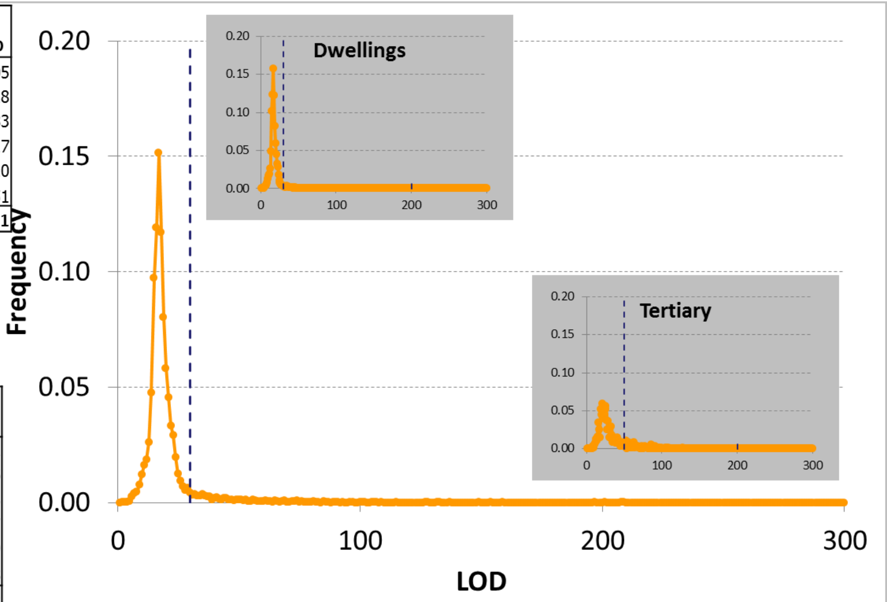


Figure 8-4: LOD Frequency diagram and MLSOA averages for CZ 70 Harrow.

Dwellings		
MLSOA	F	LOD$_D$
Westminster 008	81%	14.21
Westminster 009	97%	16.01
Westminster 012	94%	17.04
Average	**91%**	**15.76**

Tertiary		
MLSOA	F	LOD$_T$
Westminster 008	98%	27.26
Westminster 009	100%	24.02
Westminster 012	100%	22.20
Average	**99%**	**24.50**

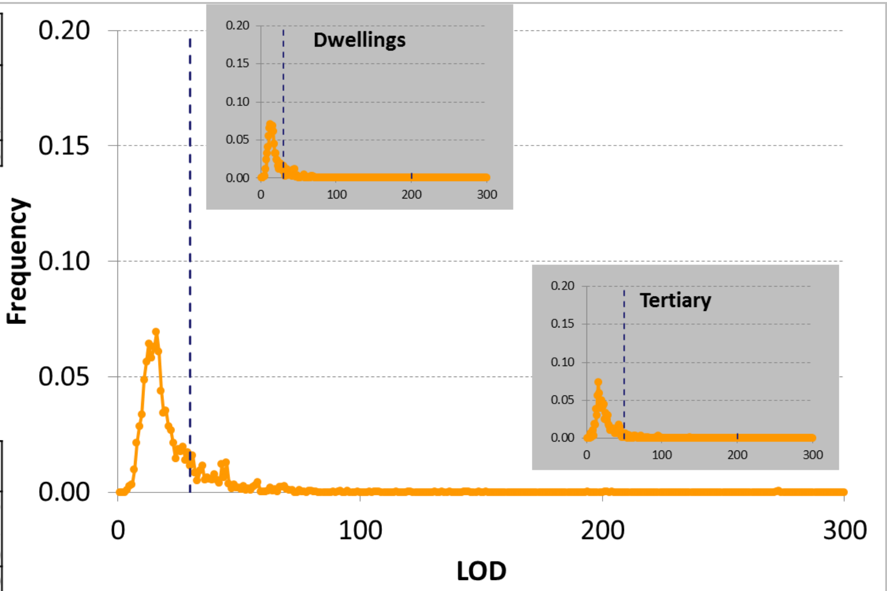


Figure 8-5: LOD Frequency diagram and MLSOA averages for CZ 148Westminster.

Dwellings		
MLSOA	F	LODD
Solihull 014	95%	21.18
Solihull 016	95%	21.13
Solihull 018	98%	19.71
Solihull 019	93%	21.51
Solihull 022	94%	19.28
Solihull 024	95%	19.12
Solihull 027	95%	19.01
Average	**95%**	**20.14**

Tertiary		
MLSOA	F	LODT
Solihull 014	80%	29.57
Solihull 016	91%	34.34
Solihull 018	100%	29.96
Solihull 019	96%	32.22
Solihull 022	90%	35.61
Solihull 024	96%	33.39
Solihull 027	88%	36.46
Average	**92%**	**33.08**

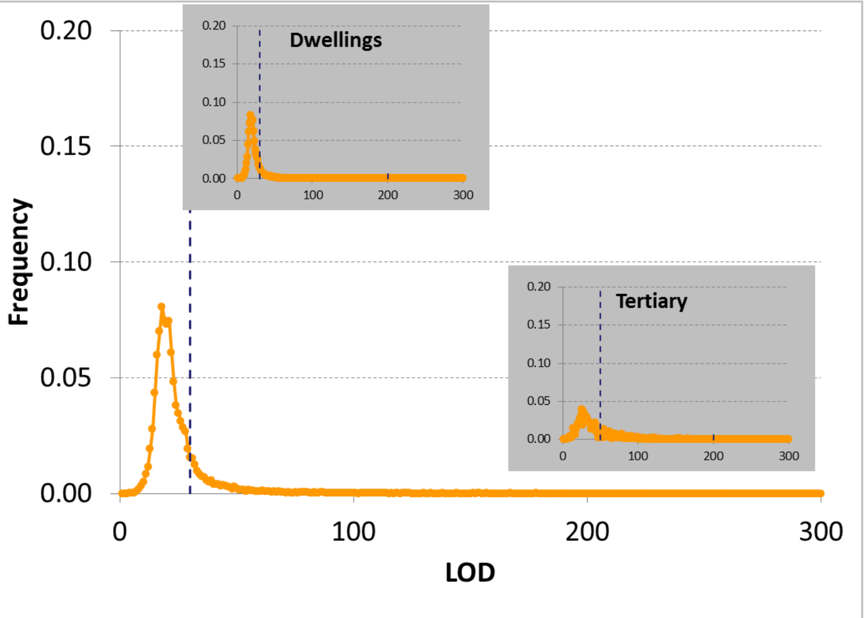


Figure 8-6: LOD Frequency diagram and MLSOA averages for CZ 313Solihull.

Applying the maximum limits to LOD which removes all the high end outliers from the analysis leads to the relation as seen from Figure 8-7.

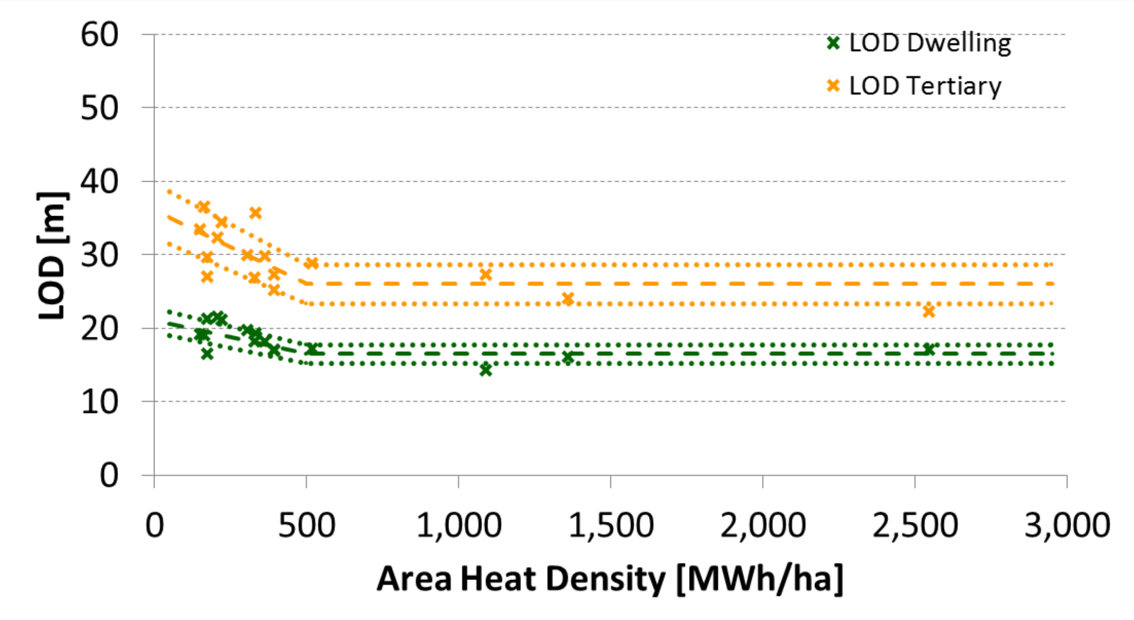


Figure 8-7: (AHD, LOD) plot with LOD maximum limit.

The SEM is reduced to 8 % and 10 % respectively which means that the relation is much more significant and reliable. It is therefore concluded that this relation is to be used by the various cost algorithms for LOD calculations in real scenarios.

(AHD, LOD) Relation for Dwellings:

AHD < 500 MWh/ha

$$LOD_D(LHD) = 21m - 0.009m \cdot \frac{ha}{MWh} \cdot AHD$$

Equation 8-3

AHD ≥ 500 MWh/ha $LOD_D = 16.5m$

Where a value of SEM = ± 8 % can be applied for sensitivity analysis.

(AHD, LOD) Relation for Tertiary:

AHD < 500 MWh/ha $LOD_T(LHD) = 36m - 0.02m \cdot \frac{ha}{MWh} \cdot AHD$ Equation 8-4

AHD ≥ 500 MWh/ha $LOD_T = 26.0m$

Where a value of SEM = ± 10 % can be applied for sensitivity analysis.

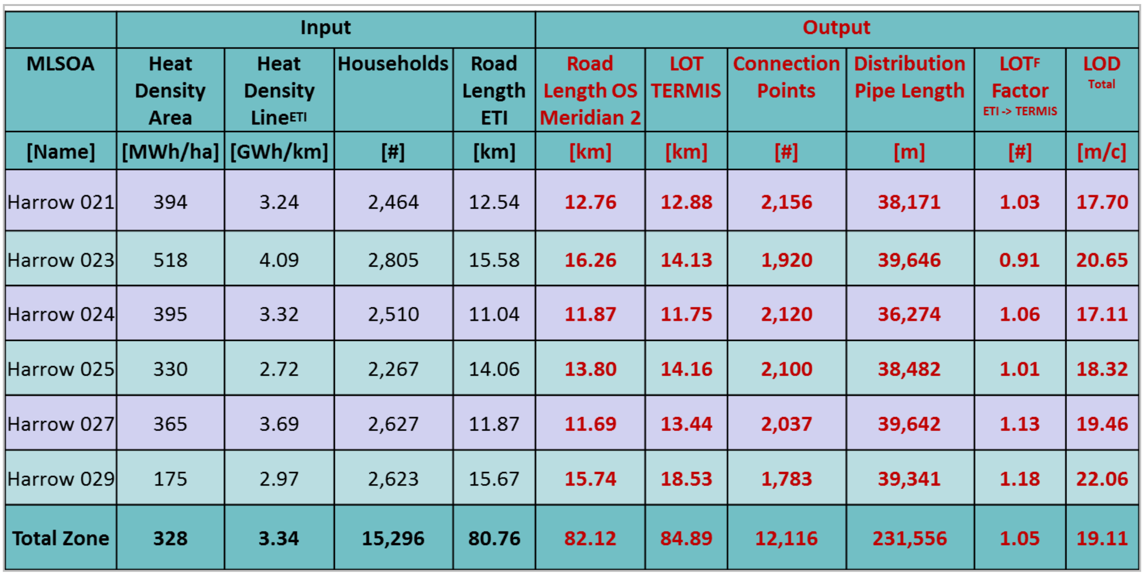
AHD to be entered in MWh/ha for both Equation 8-3 and Equation 8-4.

An (AHD, LOD) relation is hereby established with high confidence.

8.2 LOT Analysis

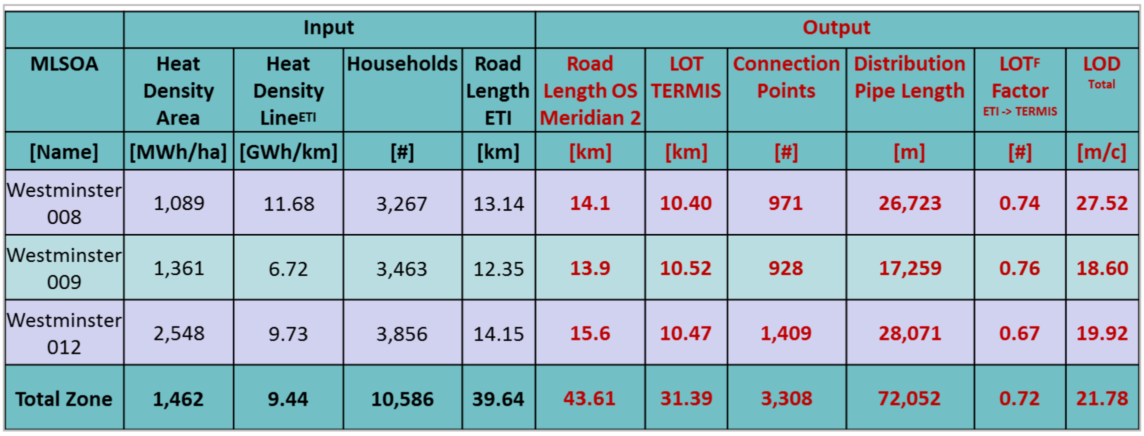
The overall results on the creation of the transmission system from road centre lines during data preparations and model build are collated into this LOT analysis. This analysis investigates if there is a relation between the total length of road centre lines from the ETI data and the expected length of transmission pipeline.

The key results for LOT, given as total values within each CZ and MLSOA, are available in Table 8-4- Table 8-6.



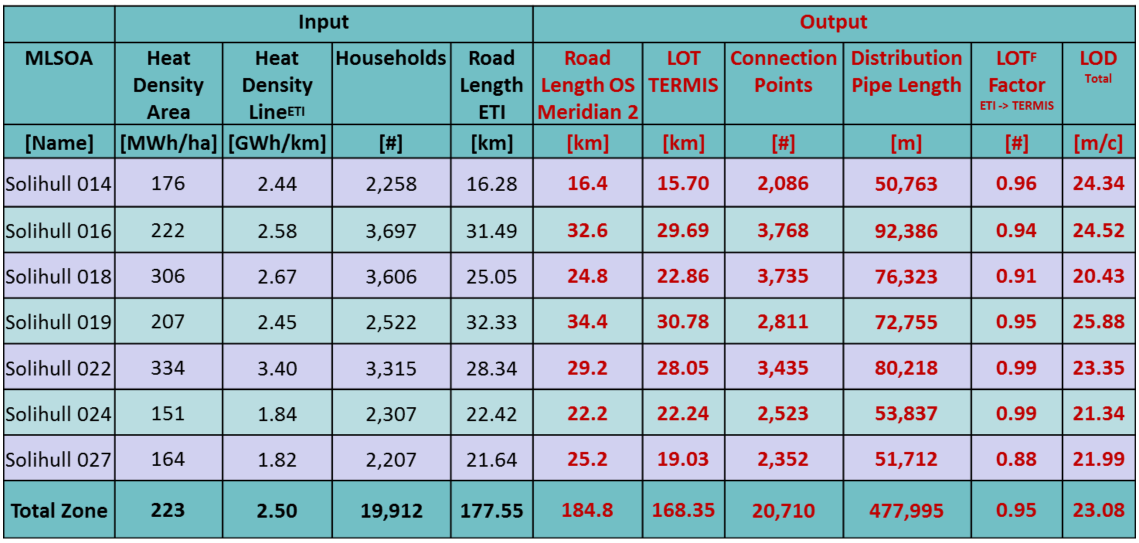
	Input				Output					
MLSOA	Heat Density Area	Heat Density Line_{ETI}	Households	Road Length ETI	Road Length OS Meridian 2	LOT TERMIS	Connection Points	Distribution Pipe Length	LOTF Factor ETI -> TERMIS	LOD Total
[Name]	[MWh/ha]	[GWh/km]	[#]	[km]	[km]	[km]	[#]	[m]	[#]	[m/c]
Harrow 021	394	3.24	2,464	12.54	12.76	12.88	2,156	38,171	1.03	17.70
Harrow 023	518	4.09	2,805	15.58	16.26	14.13	1,920	39,646	0.91	20.65
Harrow 024	395	3.32	2,510	11.04	11.87	11.75	2,120	36,274	1.06	17.11
Harrow 025	330	2.72	2,267	14.06	13.80	14.16	2,100	38,482	1.01	18.32
Harrow 027	365	3.69	2,627	11.87	11.69	13.44	2,037	39,642	1.13	19.46
Harrow 029	175	2.97	2,623	15.67	15.74	18.53	1,783	39,341	1.18	22.06
Total Zone	**328**	**3.34**	**15,296**	**80.76**	**82.12**	**84.89**	**12,116**	**231,556**	**1.05**	**19.11**

Table 8-4: LOT results for CZ 70Harrow.



	Input				Output					
MLSOA	Heat Density Area	Heat Density Line$_{ETI}$	Households	Road Length ETI	Road Length OS Meridian 2	LOT TERMIS	Connection Points	Distribution Pipe Length	LOT$_F$ Factor ETI -> TERMIS	LOD Total
[Name]	[MWh/ha]	[GWh/km]	[#]	[km]	[km]	[km]	[#]	[m]	[#]	[m/c]
Westminster 008	1,089	11.68	3,267	13.14	14.1	10.40	971	26,723	0.74	27.52
Westminster 009	1,361	6.72	3,463	12.35	13.9	10.52	928	17,259	0.76	18.60
Westminster 012	2,548	9.73	3,856	14.15	15.6	10.47	1,409	28,071	0.67	19.92
Total Zone	**1,462**	**9.44**	**10,586**	**39.64**	**43.61**	**31.39**	**3,308**	**72,052**	**0.72**	**21.78**

Table 8-5: LOT results for CZ 148Westminster.



	Input				Output					
MLSOA	Heat Density Area	Heat Density Line$_{ETI}$	Households	Road Length ETI	Road Length OS Meridian 2	LOT TERMIS	Connection Points	Distribution Pipe Length	LOT$_F$ Factor ETI -> TERMIS	LOD Total
[Name]	[MWh/ha]	[GWh/km]	[#]	[km]	[km]	[km]	[#]	[m]	[#]	[m/c]
Solihull 014	176	2.44	2,258	16.28	16.4	15.70	2,086	50,763	0.96	24.34
Solihull 016	222	2.58	3,697	31.49	32.6	29.69	3,768	92,386	0.94	24.52
Solihull 018	306	2.67	3,606	25.05	24.8	22.86	3,735	76,323	0.91	20.43
Solihull 019	207	2.45	2,522	32.33	34.4	30.78	2,811	72,755	0.95	25.88
Solihull 022	334	3.40	3,315	28.34	29.2	28.05	3,435	80,218	0.99	23.35
Solihull 024	151	1.84	2,307	22.42	22.2	22.24	2,523	53,837	0.99	21.34
Solihull 027	164	1.82	2,207	21.64	25.2	19.03	2,352	51,712	0.88	21.99
Total Zone	**223**	**2.50**	**19,912**	**177.55**	**184.8**	**168.35**	**20,710**	**477,995**	**0.95**	**23.08**

Table 8-6: LOT results for CZ 313 Solihull.

LOT$_F$ is calculated as the length of the transmission system as given from the TERMIS model divided by the length of road centre lines as given by the ETI data. LOT$_F$ is an indication of compensating for the variation in LOT created by road length as areas of low density are expected to have higher LOT than road length and vice versa.

$$LOT(HD) = LOT_F(HD) \cdot LOT_{ETI} \qquad \text{Equation 8-5}$$

Where:

LOT	The resulting length of transmission
LOT$_{ETI}$	The length of road centre lines as given from the ETI data
LOT$_F$	Road to pipe conversion factor
HD	Heat density, area or line

Plots of LOT$_F$ by AHD and LHD are available in Figure 8-8 - Figure 8-9.

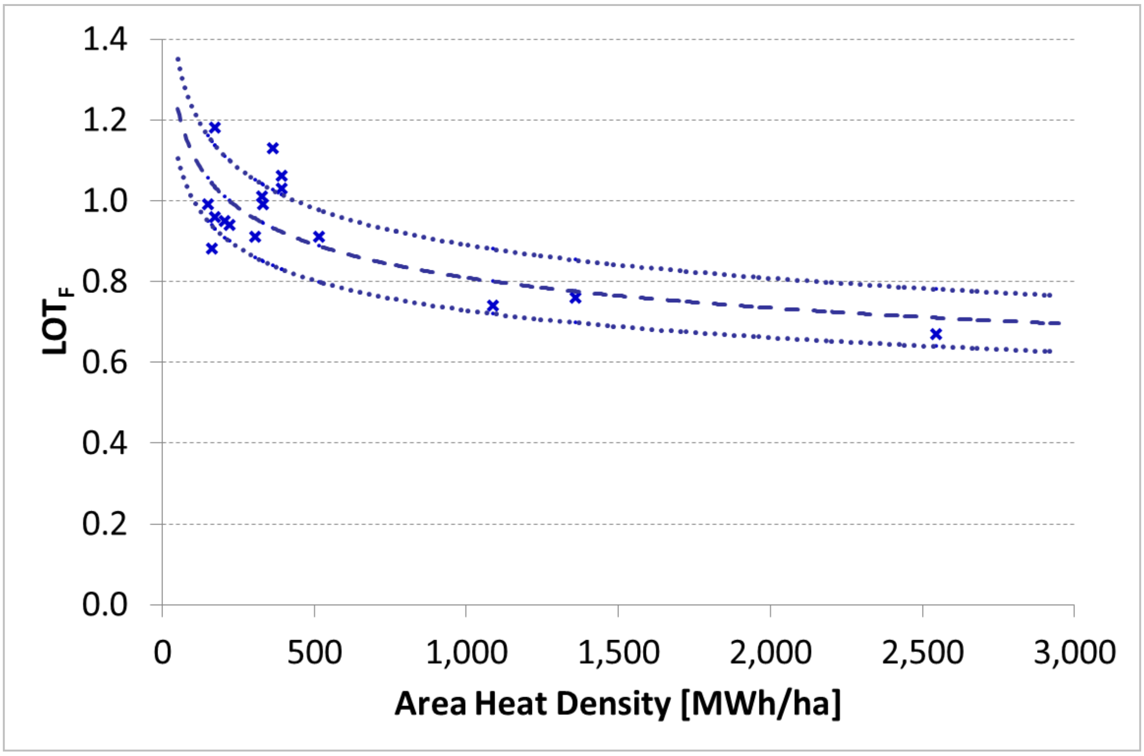


Figure 8-8:(AHD, LOT_F) plot.

SEM = ± 10 %.

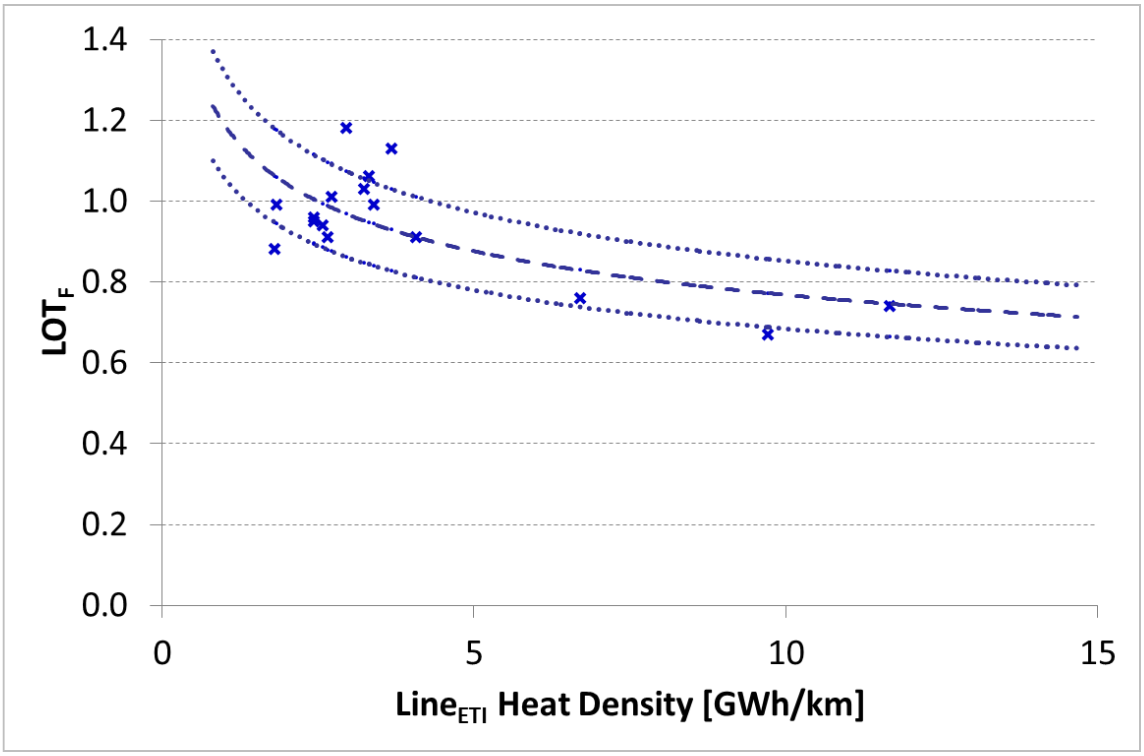


Figure 8-9:(LHD, LOT_F) plot.

SEM = ± 11 %.

No significant difference in the quality of these relations exists; meaning that it cannot be underlined that the LHD relationship is better than the AHD relationship and any of the relationships can be used with similar accuracy and results.

The (LHD, LOT$_F$) relationship is selected for further use in the cost algorithms:

$$LOT_F(LHD) = 1.19(GWh/km)^{0.19} \cdot LHD^{-0.19} \qquad \text{Equation 8-6}$$

Where a value of SEM = ± 11 % can be applied for sensitivity analysis.

LHD to be entered in GWh/km for Equation 8-6.

A (LHD, LOT) relation is hereby established with a good/high level of confidence.

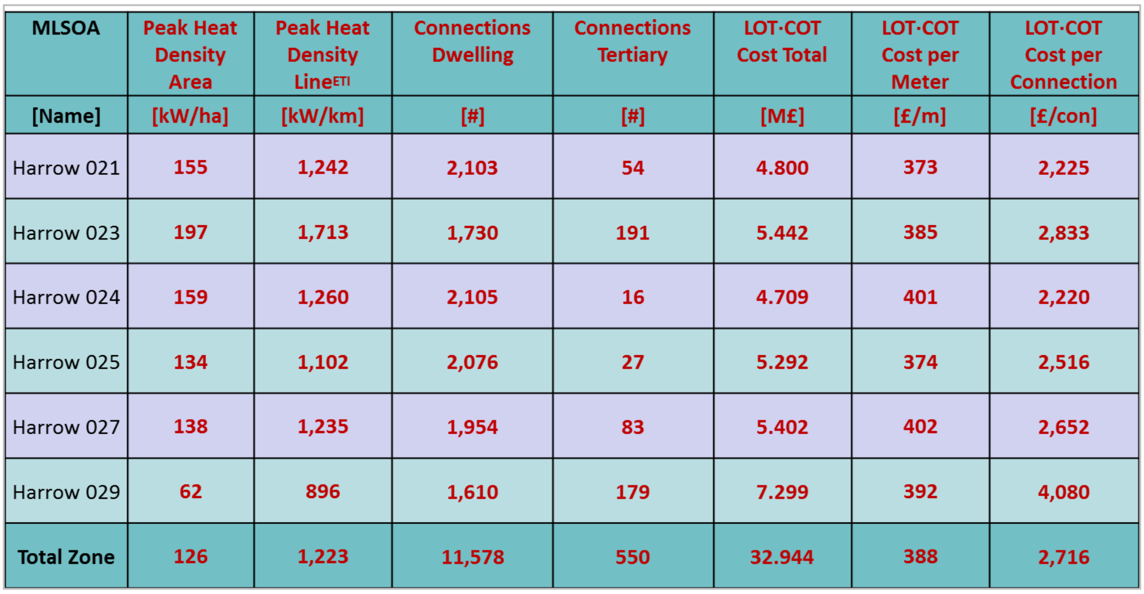
It is reasonable that higher heat density areas do not require a transmission pipe in every road as the larger buildings more common in high density areas often have a road frontage on two sides of the building.

8.3 COT Analysis

The overall results on costs of the transmission system from the pipeline dimensioning are collated into this COT analysis. This analysis investigates if there is a relationship between the cost of the transmission pipes per meter and the peak heat density.

COT is qualitatively assumed to depend on the Peak Heat Density as the Peak Heat is used for the pipe dimensioning of the transmission pipes. It is also assumed that the (LPHD, COT) relationship is more significant than the (APHD, COT) relation.

The key results for COT, given as total values and costs per meter within each CZ and MLSOA, are available in Table 8-7 - Table 8-9.



MLSOA	Peak Heat Density Area	Peak Heat Density Line$_{ETI}$	Connections Dwelling	Connections Tertiary	LOT·COT Cost Total	LOT·COT Cost per Meter	LOT·COT Cost per Connection
[Name]	[kW/ha]	[kW/km]	[#]	[#]	[M£]	[£/m]	[£/con]
Harrow 021	155	1,242	2,103	54	4.800	373	2,225
Harrow 023	197	1,713	1,730	191	5.442	385	2,833
Harrow 024	159	1,260	2,105	16	4.709	401	2,220
Harrow 025	134	1,102	2,076	27	5.292	374	2,516
Harrow 027	138	1,235	1,954	83	5.402	402	2,652
Harrow 029	62	896	1,610	179	7.299	392	4,080
Total Zone	126	1,223	11,578	550	32.944	388	2,716

Table 8-7: COT results for CZ 70 Harrow.

MLSOA	Peak Heat Density Area	Peak Heat Density Line$_{ETI}$	Connections Dwelling	Connections Tertiary	LOT·COT Cost Total	LOT·COT Cost per meter	LOT·COT Cost per Connection
[Name]	[kW/ha]	[kW/km]	[#]	[#]	[M£]	[£/m]	[£/con]
Westminster 008	448	6,067	766	205	5.525	531	5,690
Westminster 009	474	2,747	724	204	4.262	405	4,593
Westminster 012	991	5,110	1,192	217	4.649	444	3,300
Total Zone	566	4,613	2,682	626	14.436	460	4,364

Table 8-8: COT results for CZ 148Westminster.

MLSOA	Peak Heat Density Area	Peak Heat Density Line$_{ETI}$	Connections Dwelling	Connections Tertiary	LOT·COT Cost Total	LOT·COT Cost per meter	LOT·COT Cost per Connection
[Name]	[kW/ha]	[kW/km]	[#]	[#]	[M£]	[£/m]	[£/con]
Solihull 014	63	904	2,040	46	6.081	387	2,915
Solihull 016	77	950	3,606	162	11.407	384	3,027
Solihull 018	110	1,045	3,682	53	8.606	376	2,304
Solihull 019	71	880	2,565	246	12.828	417	4,564
Solihull 022	116	1,187	3,255	180	11.803	421	3,436
Solihull 024	51	621	2,474	49	8.478	381	3,360
Solihull 027	54	683	2,284	68	7.115	374	3,025
Total Zone	77	911	19,906	804	66.318	394	3,202

Table 8-9: COT results for CZ 313Solihull.

Plots of COT by APHD and LPHD are available in Figure 8-10 - Figure 8-11.

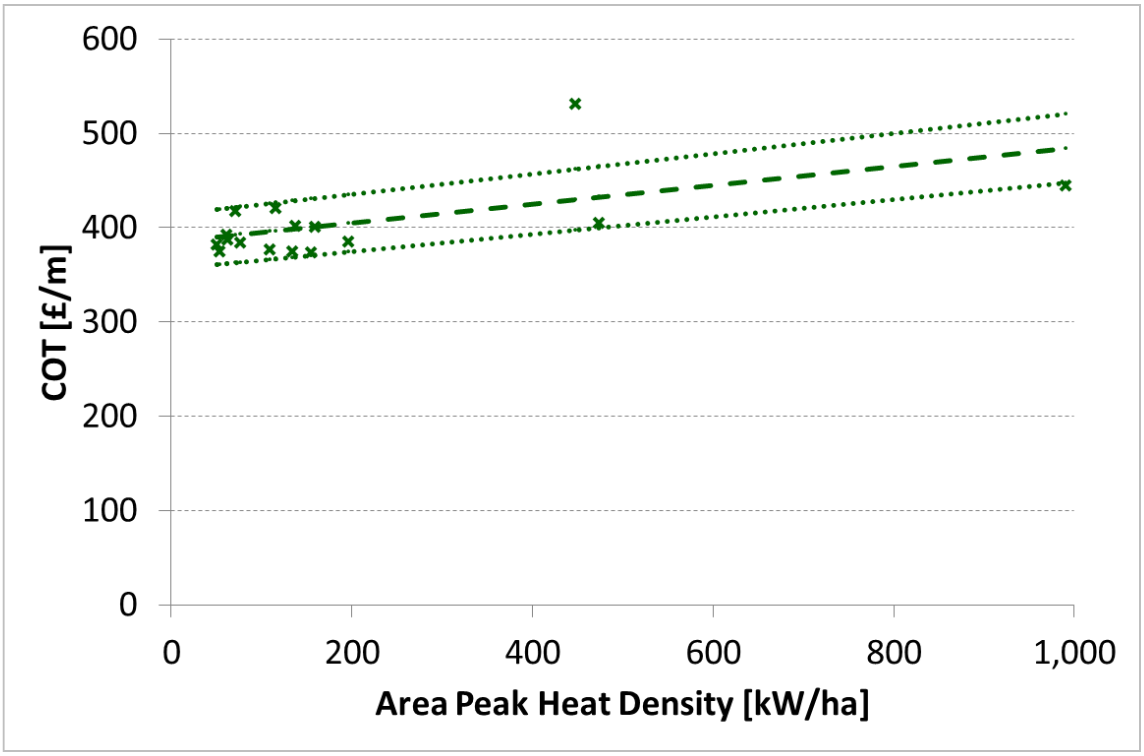


Figure 8-10: (APHD, COT) plot.

SEM = ± 8 %.

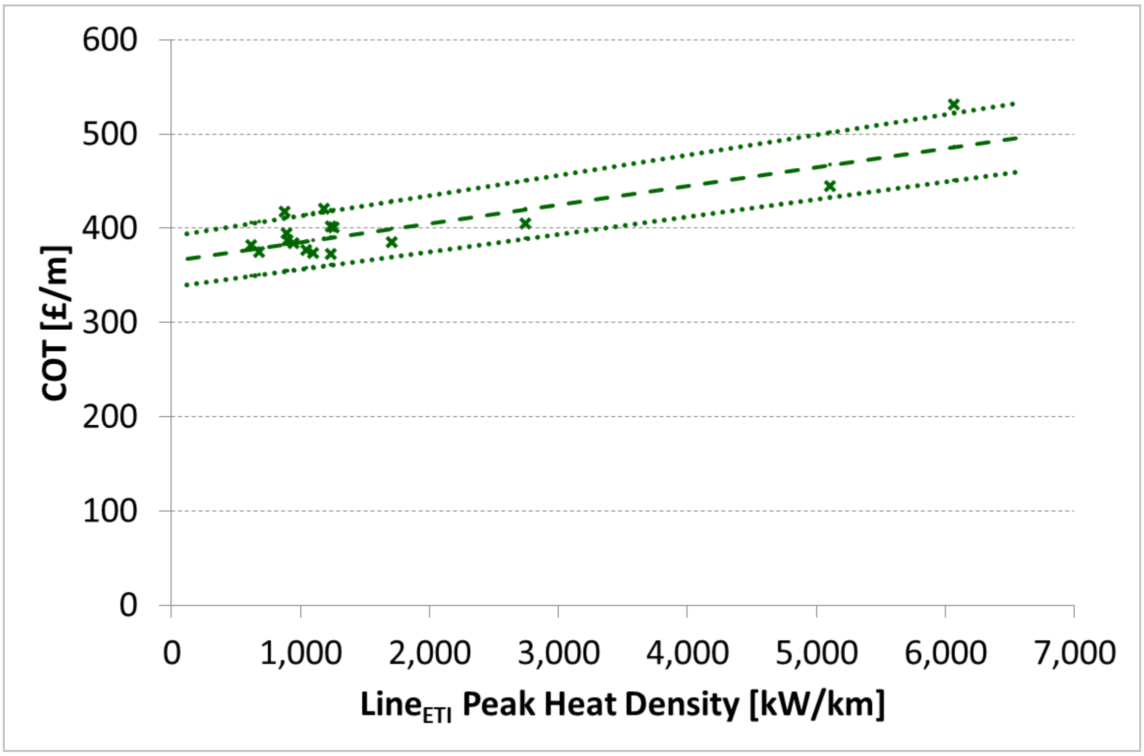


Figure 8-11: (LPHD, COT) plot.

SEM = ± 7 %.

No significant difference in the quality of these relationships exists; meaning that it cannot be underlined that the LPHD relationship is better than the APHD relationship and any of the relations can be used with similar accuracy and results.

However as the SEM is slightly smaller for the LPHD case, the (LPHD, COT) relationship is selected for further use in the cost algorithms:

$$COT(LPHD) = 365\frac{£}{m} + 20\frac{£}{kW} \cdot LPHD \qquad \text{Equation 8-7}$$

Where a value of SEM = ± 7 % can be applied for sensitivity analysis.

LPHD to be entered in kW/m for Equation 8-7.

A (LPHD, COT) relationship is hereby established with a high level of confidence.

8.4 Heat Loss Analysis

Annual heat loss from the transmission pipe system as calculated under section 7.2 has been extracted and calculated into a percentage loss for each MLSOA, both by heat production and by heat demand. The percentage by heat demand relationship is the target of the analysis as this can be used further by the cost models.

Plots of Heat Loss (ΔE) by LHD are available Figure 8-12 - Figure 8-13.

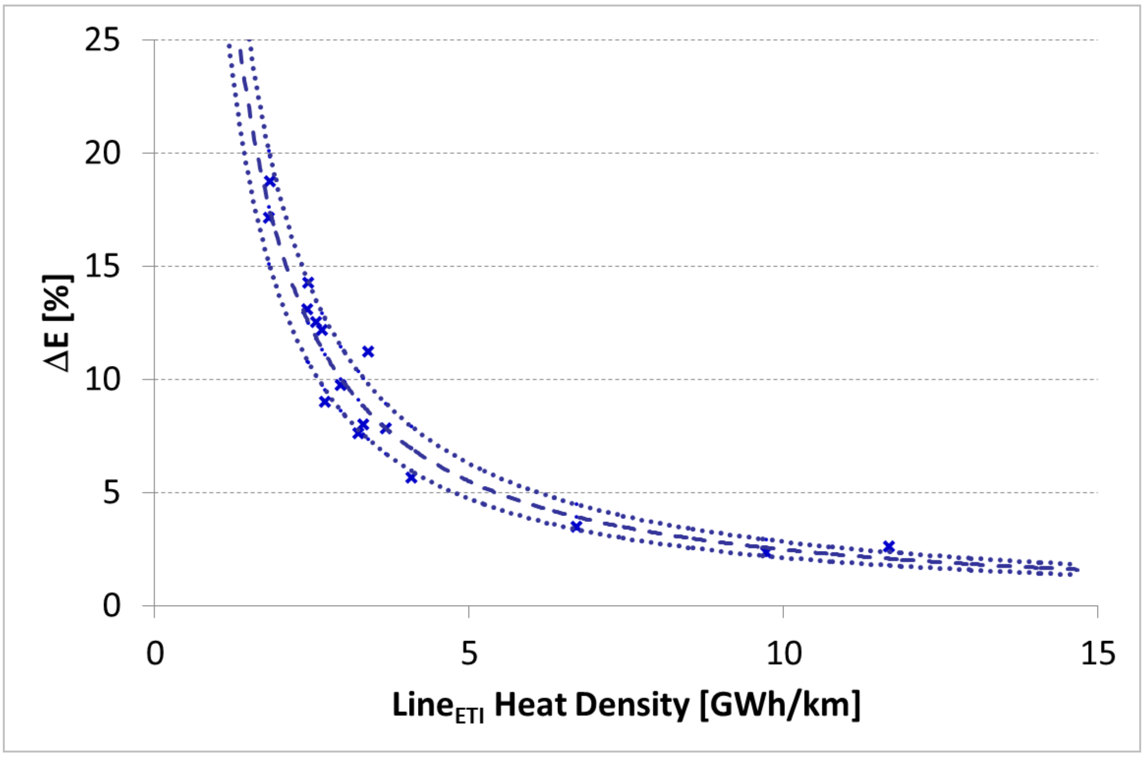


Figure 8-12: (LHD, ΔE) plot based on total heat supplied.

SEM = ± 14 %.

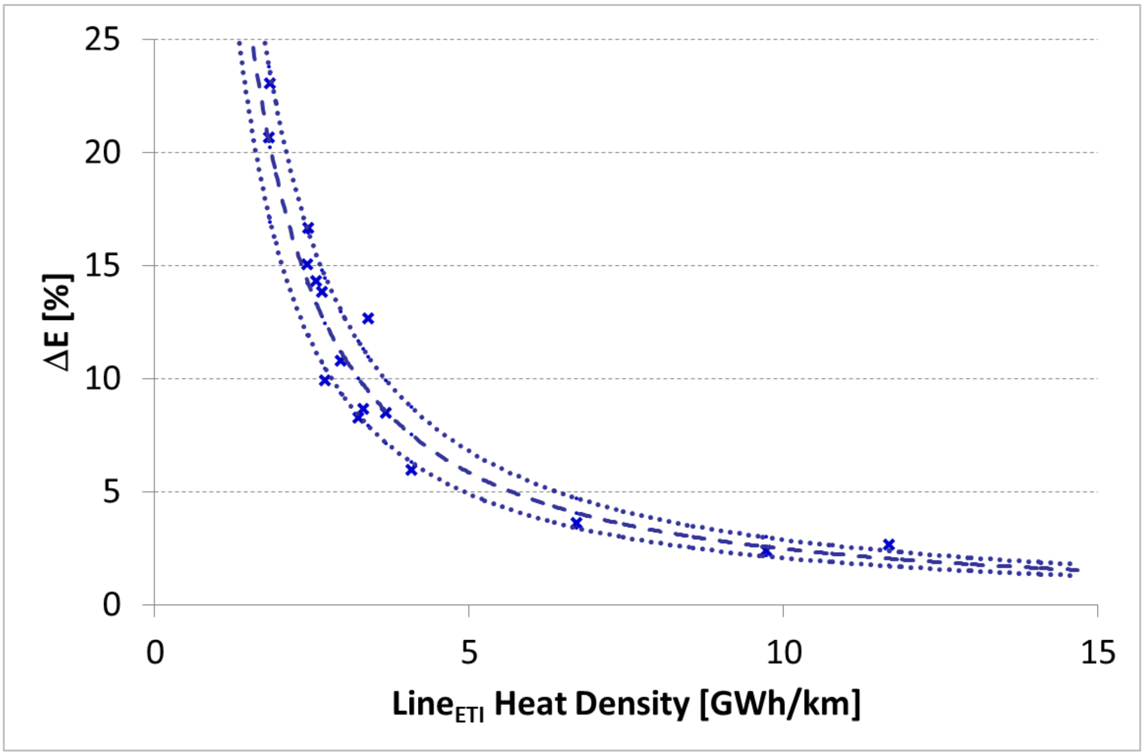


Figure 8-13: (LHD, ΔE) plot based on total heat demand.

SEM = ± 16 %.

Even though the heat loss is estimated better, but not significantly, as a percentage of heat supplied, the relationship based on heat demand is used as this can be directly implemented into the cost models.

The (LHD, ΔE) relation is selected for further use in the cost algorithms:

$$\Delta E(LHD) = \ 43\,\%\,(GWh/km)^{1.24}\ \cdot LHD^{-1.24} \qquad \text{Equation 8-8}$$

Where a value of SEM = ± 16 % can be applied for sensitivity analysis.

LHD to be entered in GWh/km for Equation 8-8.

A (LHD, ΔE) relationship is hereby established with a good level of confidence.

8.5 Pumping Power Requirement Analysis

The pumping power requirements for supplying the required heat demand throughout the year as calculated under section 7.2 has been extracted and calculated into a percentage by heat demand for each CZ. The percentage by heat demand relationship is the target of the analysis as this can be used further by the cost models.

Plot of Pumping Power Requirement (E) as a percentage of heat demand by LHD is available in Figure 8-14.

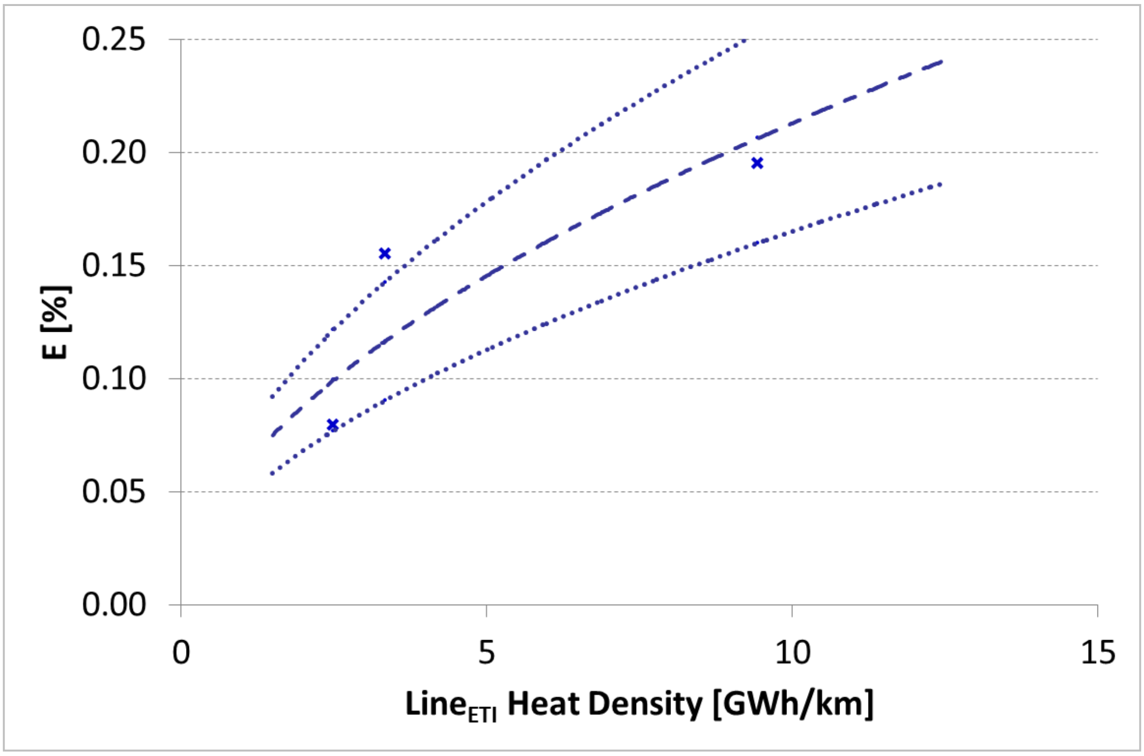


Figure 8-14: (LHD, E) plot.

The data basis is too limited to generate a relation.

Efficiency of pumps and motors etc. are not included in this analysis. E is the required output of the pump. Pump power consumption has to be calculated by applying efficiency factors.

By comparing to reference values as reported by Danish district heating companies it is assumed that an effective pumping power consumption of 0.5 % of the heat demand is realistic, considering that new schemes in GB would be based on the latest pump technology. As this is a relatively small value it was decided that there was no need to derive a relationship and the figure 0.5% could be used throughout for all CZs as a conservative assumption.

9 DHN COSTS CALCULATIONS

The cost algorithm has changed several times during this project as it developed with the requirements about the accuracy of the DHN cost for the zones. The first algorithm presented in Ref. 1 and the simplified algorithm presented in Ref. 3, and available in 12.4 Appendix 4 – Simplified Algorithm, did not meet the expectations. Therefore a revised and more detailed algorithm has been developed, which is presented in this chapter.

Utilizing the results obtained in the previous sections total costs of DHN for all 20 CZs is calculated. Cost calculations are carried out for the MLSOAs and summarized to CZ level. Costs are calculated using the Simplified Algorithm, TERMIS (only for the 3 CZs included in the sample) and the Revised Algorithm for comparison and evaluation.

The Revised Algorithm is a refinement of the Detailed Algorithm which includes the TERMIS results and combines this with data from ADF/EIFER which includes more details on building classification and distribution than available from GIS.

9.1 DHN Cost Algorithm

The DHN cost of each of characteristic zone in the sample is calculated in two steps. First the costs of each MLSOA within the characteristic zones are calculated according to the formulas given in section 9.1.1 and afterwards the costs of the MLSOAs of CZ are summed up.

9.1.1 Calculation per MLSOA

The MLSOA costs are created out of three different parts:

1. Cost for the transmission pipes COT.
2. Cost for the distribution pipes COD.
3. Cost for the hydraulic interface units HIU Cost.

Calculation of DHN cost per MLSOA:

$$Cost_{MLSOA} = COT_{Total} + COD_{Total} + HIU\ Cost_{Total} \qquad \text{Equation 9-1}$$

Where:

$$COT_{Total} = LOT_{ETI} * LOT_{F,LHD} * COT_{LPHD} \qquad \text{Equation 9-2}$$

$$\begin{aligned} COD_{Total} = MP \cdot [&LOD_D \cdot COD_D \\ &\cdot Max\{\#SB - ½ \cdot \#SDH - ½ \cdot \#TH; ½ \cdot \#SB\} \\ &+ LOD_T \cdot COD_T \cdot \#LB] \end{aligned} \qquad \text{Equation 9-3}$$

$$HIU\ Cost_{Total} = MP \cdot [HIU_{Apartment} * \#AP + HIU_{House} * \#SB + HIU_{Tertiary} * \#\ LB] \quad \text{Equation 9-4}$$

With:

#SB	Count of small buildings, given by Emapsite
#LB	Count of large buildings, given by Emapsite
#AP	Count of apartments, given by EDF/EIFER
#SDH	Count of semi-detached houses, given by EDF/EIFER
#TH	Count of terraced houses, given by EDF/EIFER

9.1.2 Input Data & Assumptions

Input data are taken from the previous sections 7 - 8 combined with the additional data and information defined and assumptions made in this section.

For semi-detached houses and terraced houses it is assumed that they share one connection for each two buildings; with the limitation that this value can only be decreased to half the number of small buildings. In the end, this total summation is multiplied with the market penetration which is set to 80 %.

The numbers of HIUs are provided by Emapsite for the number of houses and number of tertiary buildings. Additionally, the number of apartments is provided by EDF as described in Ref. 4.

The number of different building and dwelling data are provided by different sources, Emapsite and EDF/EIFER. The number of small buildings with a surface area below 200 m² and the number of large buildings with a surface area of more than 200 m² are provided by Emapsite and used to calculate COD and HIU cost. The other three data sets are provided by EDF/EIFER and used to calculate the HIU cost (number of apartments) or to calculate the number of residential connections and the length of distribution pipes needed to connect them (number of semi-detached houses and number of terraced houses).

The market penetration MP has been set to be 80 %.

9.1.3 Calculation per Characteristic Zone

Once the costs for the DHN network of all MLSOAs within one CZ are calculated, these costs are cumulated to determine the total DHN cost of the CZ. This step is repeated for all 20 CZs.

$$Total\ DHNCost_{CZ} = \sum_{MLSOAs\ of\ CZ} DHN\ Cost_{MLSOA} \quad \text{Equation 9-5}$$

9.2 Cost Results and Interpretation

Cost results are generated on MLSOA level, section 9.2.1, which is then cumulated on CZ level, section 9.2.2. Cost calculations have been carried out assuming:

1. Individual connections and 100 % market penetration.
2. Shared connections and 80 % market penetration.

9.2.1 Results for Sample MLSOAs

In the first step, the DHN cost for the 16 sample MLSOAs has been calculated assuming individual connections and 100 % market penetration. In general, there is a good coherence between the total cost of the Revised Algorithm and the cost determined by including TERMIS, which would be expected.

Compared to the simplified algorithm the difference can become quite large, which is mainly driven by a difference in the HIU cost and by an extensive overestimation of the transmission pipe cost. Especially in very dense areas, which are dominated by tertiary demand, this effect can be easily seen. The three MLSOAs of CZ 148 Westminster are good examples for this huge decrease in cost, see Table 9-1. This Table 9-1 shows the results for a 1:1 comparison between the three approaches as it assumes a single distribution pipe per building and 100 % market penetration.

MLSOA	Revised Algorithm	TERMIS	Simplified Algorithm	$\frac{\text{Revised}}{\text{Simplified}}$	$\frac{\text{TERMIS}}{\text{Simplified}}$	$\frac{\text{Revised}}{\text{TERMIS}}$
[Name]	[£]	[£]	[£]	[%]	[%]	[%]
Harrow 021	23,253,000	21,237,000	22,435,000	104	95	109
Harrow 023	21,765,000	21,848,000	48,072,000	45	45	100
Harrow 024	22,080,000	20,396,000	17,849,000	124	114	108
Harrow 025	22,692,000	20,616,000	24,512,000	93	84	110
Harrow 027	22,527,000	22,219,000	21,660,000	104	103	101
Harrow 029	23,809,000	23,449,000	31,037,000	77	76	102
Westminster 008	13,481,000	16,261,000	75,221,000	18	22	83
Westminster 009	13,015,000	12,066,000	42,578,000	31	28	108
Westminster 012	17,293,000	16,649,000	85,825,000	20	19	104
Solihull 014	25,423,000	25,276,000	22,690,000	112	111	101
Solihull 016	45,973,000	46,560,000	46,142,000	100	101	99
Solihull 018	41,175,000	38,642,000	39,219,000	105	99	107
Solihull 019	39,075,000	40,500,000	44,091,000	89	92	96
Solihull 022	40,543,000	43,133,000	52,509,000	77	82	94
Solihull 024	31,758,000	29,313,000	23,627,000	134	124	108
Solihull 027	30,112,000	27,206,000	23,527,000	128	116	111

Table 9-1: Total MLSOA costs, 100 % market penetration, individual connections.

The total costs, recalculated into cost per heat demand, are plotted by heat density in Figure 9-1.

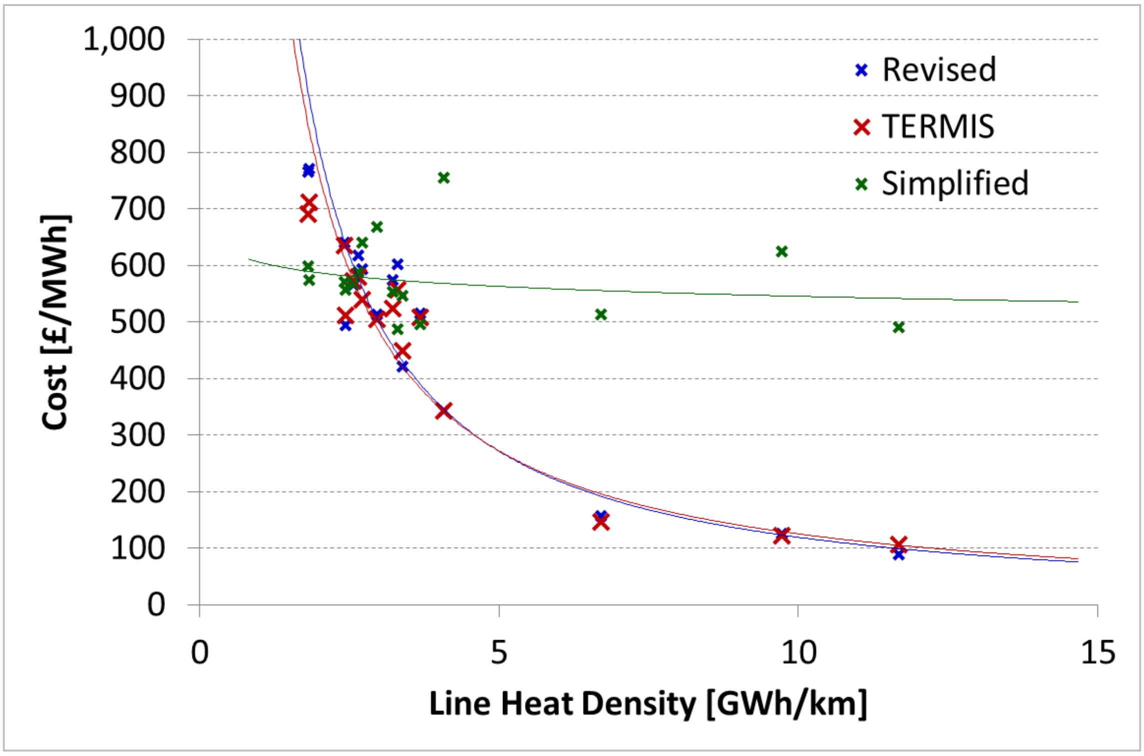


Figure 9-1: Cost relations for MLSOAs, 100 % market penetration, individual connections.

It is clearly seen that the Simplified Algorithm is overestimating the total cost in high density areas. It is further observed, that by implementing the results of the TERMIS modelling into the Revised Algorithm leads to a high confidence between these two approaches. As a result, the Revised Algorithm can be used with confidence for estimating costs for the remaining Characteristic Zones.

Table 9.2 shows the results for the three approaches using the shared connection assumption and 80 % market penetration. The results of the Revised Algorithm are about 25 % lower on average than the TERMIS results which can be explained by the number of semi-detached and terraced houses that are assumed to share a connection.

MLSOA	Revised Algorithm	TERMIS	Simplified Algorithm	Revised / Simplified	TERMIS / Simplified	Revised / TERMIS
[Name]	[£]	[£]	[£]	[%]	[%]	[%]
Harrow 021	15,226,000	20,217,000	22,435,000	68	90	75
Harrow 023	14,544,000	20,972,000	48,072,000	30	44	69
Harrow 024	14,752,000	19,402,000	17,849,000	83	109	76
Harrow 025	14,851,000	19,840,000	24,512,000	61	81	75
Harrow 027	14,834,000	21,211,000	21,660,000	68	98	70
Harrow 029	15,837,000	22,614,000	31,037,000	51	73	70
Westminster 008	9,901,000	15,754,000	75,221,000	13	21	63
Westminster 009	9,502,000	11,578,000	42,578,000	22	27	82
Westminster 012	12,025,000	15,955,000	85,825,000	14	19	75
Solihull 014	17,708,000	24,458,000	22,690,000	78	108	72
Solihull 016	33,162,000	45,066,000	46,142,000	72	98	74
Solihull 018	28,544,000	37,151,000	39,219,000	73	95	77
Solihull 019	30,730,000	39,356,000	44,091,000	70	89	78
Solihull 022	29,217,000	41,688,000	52,509,000	56	79	70
Solihull 024	25,716,000	28,340,000	23,627,000	109	120	91
Solihull 027	24,567,000	26,274,000	23,527,000	104	112	94

Table 9-2: Total MLSOA costs, 80 % market penetration, shared connections.

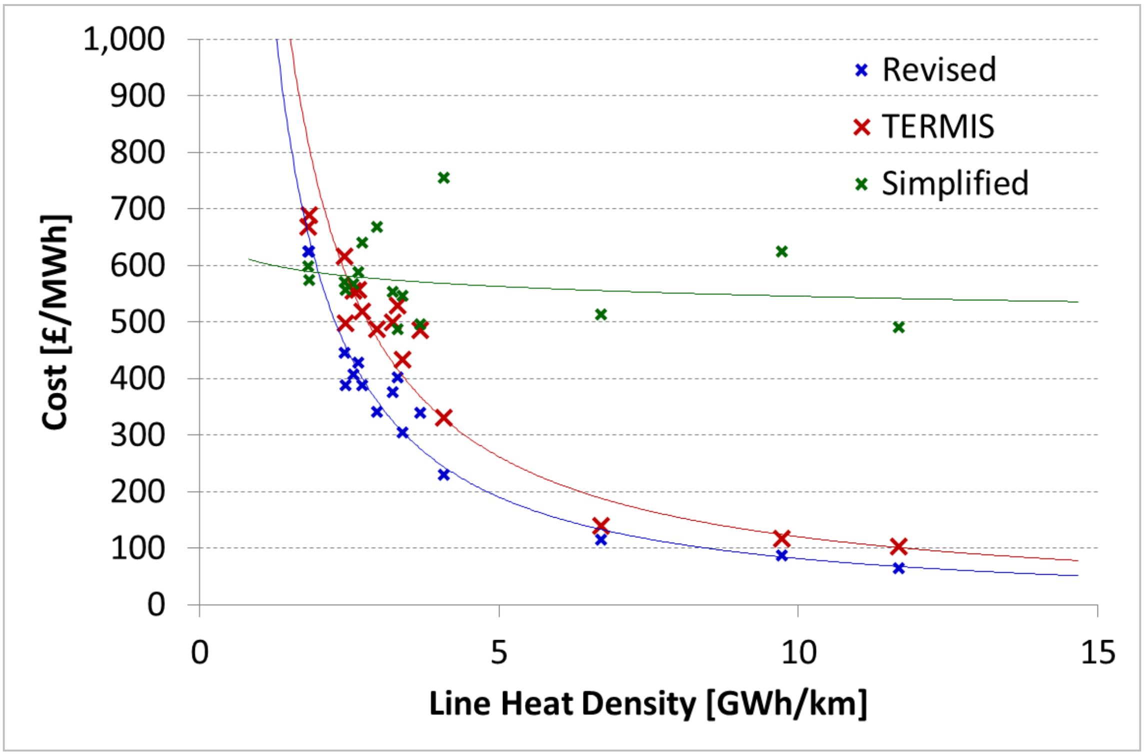


Figure 9-2: Cost relations for MLSOAs, 80 % market penetration, shared connections.

9.2.2 Results for Characteristic Zones

The calculations are extended to cover all 20 Characteristic Zones, refer to Table 9-3 which also includes the classes that the CZs are representing. The results for the TERMIS approach have been added for the three sample CZs.

Class	Zone	Revised Algorithm	TERMIS	Simplified Algorithm	$\frac{\text{Revised}}{\text{Simplified}}$
[#]	[#]	[£]	[£]	[£]	[%]
1	147	11,435,000		203,047,000	6
2	711	150,553,000		155,844,000	97
3	239	126,902,000		133,005,000	95
4	619	124,025,000		223,366,000	56
5	**70**	**90,042,000**	**124,254,000**	**165,565,000**	54
6	509	153,020,000		188,435,000	81
7	127	208,146,000		268,868,000	77
8	145	94,103,000		139,633,000	67
9	29	68,841,000		259,604,000	27
10	138	143,499,000		196,854,000	73
11	566	63,694,000		63,844,000	100
12	**313**	**189,644,000**	**242,333,000**	**251,807,000**	75
13	686	79,975,000		98,018,000	82
14	535	21,809,000		21,665,000	101
15	734	32,650,000		33,821,000	97
16	**148**	**31,428,000**	**43,286,000**	**203,624,000**	15
17	23	121,705,000		167,322,000	73
18	547	121,156,000		150,239,000	81
19	701	164,464,000		192,301,000	86
20	909	15,251,000		13,218,000	115

Table 9-3: Total CZ costs, 80 % market penetration, shared connections.

The pattern is the same as for the individual MLSOAs, which is expected as the CZs are aggregations of the MLSOAs. The accuracy of the simple algorithm is good for the average zones with lower densities like the CZs of class 2 and 3, but the cost accuracy weakens for high density area like in class 1 and 16. This can again be explained by the overestimation of cost of the transmission pipe work and an extensive number of HIUs. The ratio between the Revised and Simplified Algorithm is plotted in Figure 9.3.

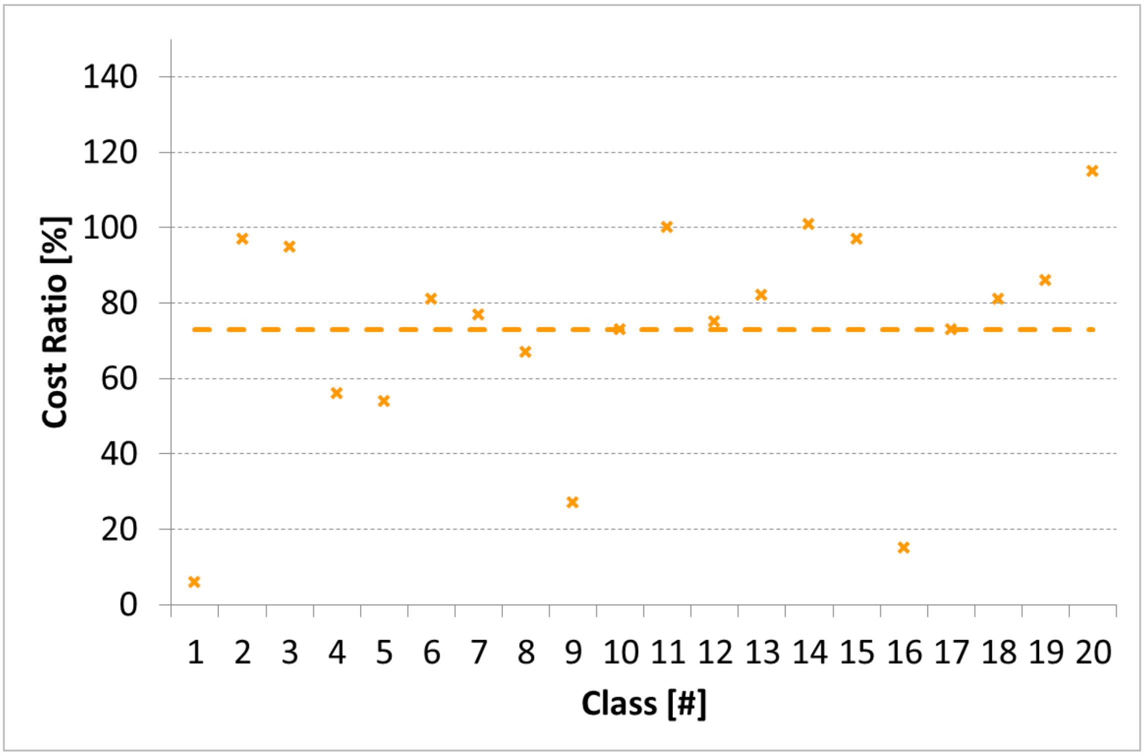


Figure 9-3: Cost ration between Revised and Simplified Algorithm for all CZs.

It can be concluded that the Revised Algorithm is showing a high accuracy to the real estimated costs using the design tool TERMIS. There is an overestimation of about 25 % by TERMIS which goes back to a smaller number of connections needed to supply semi-detached houses and terraced houses. The sharing of connections by these house types could not have been allowed for in TERMIS as the required information is unavailable in the GIS data available. Compared to the Simplified Algorithm, the new Revised Algorithm is showing more or less the same figures for zones at the lower end of the boundary conditions for energy density of 200,000 kWh/ha. On the other hand, the cost estimation for high density and tertiary dominated zones is much too high. Here zone 148 of class 16, which was analysed within TERMIS, clearly shows the discrepancy between the three methods (see Table 9-3).

10 TECHNICAL CONCLUSION

In order to verify, strengthen and refine the cost algorithms as developed in Ref. 1 a DHN modelling tool, TERMIS, has been applied for constructing DHN models based on GIS road centre lines and buildings layers, By combining the GIS data with information on heat demand a preliminary design model of each involved area has been build and configured and used to conduct various simulations to generate results on distribution pipe length, sizing of transmission pipes, cost of transmission pipes, heat loss and pumping power requirements.

This paper has developed empirical relations (formulas) for calculation of a subset of parameters used in the cost algorithms. Specifically the following relations have been developed:

10.1 LOD$_D$ Relation -Dwellings

AHD < 500 MWh/ha $$LOD_D(LHD) = 21m - 0.009m \cdot \frac{ha}{MWh} \cdot AHD$$ Equation 10-1

AHD ≥ 500 MWh/ha $$LOD_D = 16.5m$$

Where a value of SEM = ± 8 % means the relation is established with high confidence.

10.2 LOD$_T$ Relation -Tertiary

AHD < 500 MWh/ha $$LOD_T(LHD) = 36m - 0.02m \cdot \frac{ha}{MWh} \cdot AHD$$ Equation 10-2

AHD ≥ 500 MWh/ha $$LOD_T = 26.0m$$

Where a value of SEM = ± 10 % means the relation is established with good/high confidence.

10.3 LOT Relation

$$LOT(LHD) = 1.19(GWh/km)^{0.19} \cdot LHD^{-0.19} \cdot LOT_{ETI}$$ Equation 10-3

Where a value of SEM = ± 11 % means the relation is established with good/high confidence.

10.4 COT Relation

$$COT(LPHD) = 365\frac{£}{m} + 20\frac{£}{kW} \cdot LPHD$$ Equation 10-4

Where a value of SEM = ± 7 % means the relation is established with high confidence.

10.5 Heat Loss Relation

$$E_{HL}(LHD) = 0.43\ (GWh/km)^{2.24} \cdot LHD^{-1.24} \qquad \text{Equation 10-5}$$

Where a value of SEM = ± 16 % means the relation is established with good confidence.

10.6 Pumping Energy

$$E_{PE}(LHD) = 0.005 \cdot km/GWh \cdot LHD \qquad \text{Equation 10-6}$$

Overall Conclusion

The relationships derived show that the Revised Algorithm as now constructed will provide a suitable method for estimating costs for all CZs using cost book data derived for the UK and based on actual DH designs produced using standard design software for 3 sample areas in the UK.

There is a strong relationship with line heat density and the use of GIS data on road length together with statistics on fuel use in a given area would enable a first estimate of DH costs to be made for any MLSOA in the UK.

Figure 10.1 below shows the TERMIS curve which represents the costs for schemes using actual designs and the Revised Algorithm costs which assumes an 80% market penetration and shared connections for terraces and semi-detached houses. This is a significant improvement on the accuracy of the Simplified Algorithm which was derived from more limited data and over estimated costs in high density areas.

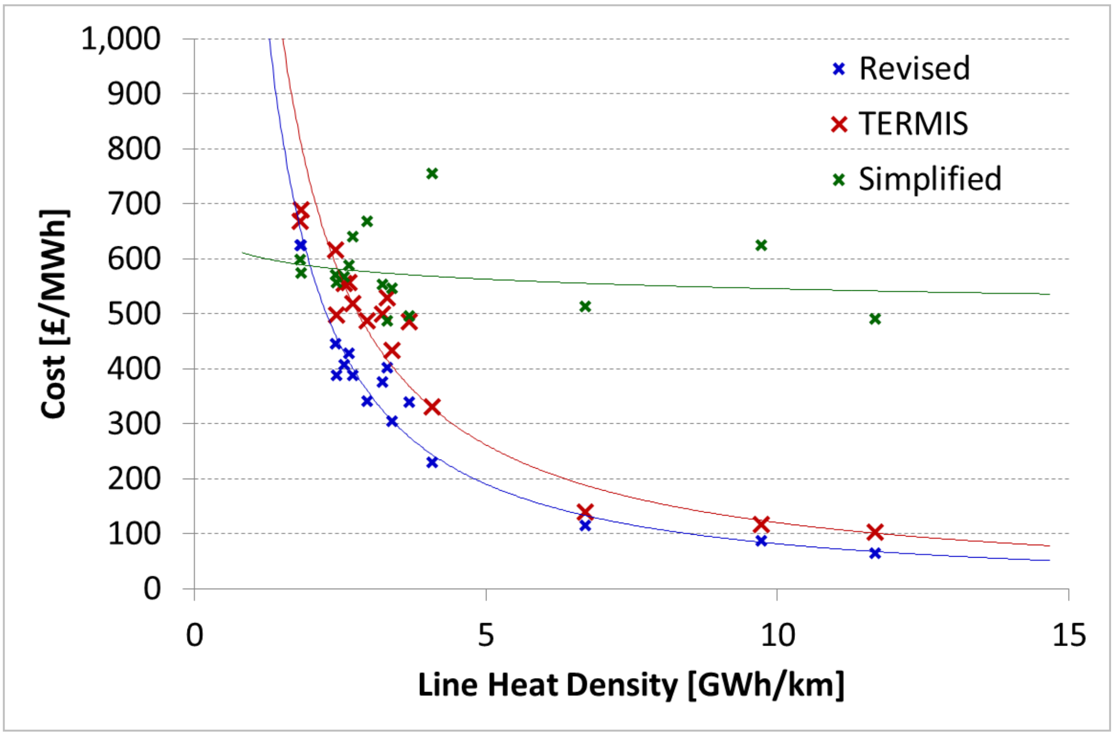


Figure 10.1 – Revised Cost Algorithm for District Heating Network capital costs

11 REFERENCES

Ref. 1: Mooney Kelly NIRAS, 2012. *D.H. Construction Costs in the UK*. London, Report for ETI Macro DE Project

Ref. 2: Devore, J. L., 1995, *Probability and Statistics for Engineering and the Sciences*, 4th ed. California Polytechnic State University, San Luis Obispo: Wadsworth

Ref. 3 Meidl, P. et al., 2012, *Energy Demand Analysis in GB*, Karlsruhe, Paris and Manchester, Report for the ETI Macro DE Project

Ref. 4 McKoen, K., A. Koch, et al., 2011, *Development of a methodology to calculate energy demand*. Karlsruhe and Paris, Report for the ETI Macro DE Project

12 APPENDICES

The following appendices are attached:

- Appendix 1 – Assumptions
- Appendix 2 – Cost Reports
- Appendix 3 – Heat Demands
- Appendix 4 - Simplified Algorithm
-

12.1 Appendix 1 – Assumptions

12.1.1 Assumption1 - Sample Size.

It is assumed that a sample size of 15 - 20 MLSOAs will be adequate to represent the full population of 91 MLSOAs. This assumption is based on the general rule that a sample size of 1/10 of the population is “large enough” combined with the rule of thumb that a sample size should amount to 30 in order to fulfil the central limit theorem. By further having a carefully matched sample instead of a randomly selected sample the assumption is further underlined as valid.

12.1.2 Assumption 2 – Building Classification

Buildings are classified as follows:

Area	**Classification**	**Heat Demand Factor**	**Note**
[m²]	**[Class]**	**[-]**	**[]**
0 - 30	Outhouse	0	No heat demand
30 - 200	Dwellings	1	Heat demand scaled by building area
200 -	Tertiary	1	Heat demand scaled by building area

Table 12-1: Building classification.

This approach is limited by the fact that only the ground floor plan area and perimeter length are available from GIS for the building polygons. No detailed information on building type or number of storeys is available. The assumption is based on frequency plots of building areas and UK building regulations.

According to UK building regulations 30 m² is the upper limit for not requiring planning permission for buildings.

Frequency plots of building areas for the three CZ’s are shown below in Figure 12-1 - Figure 12-3.

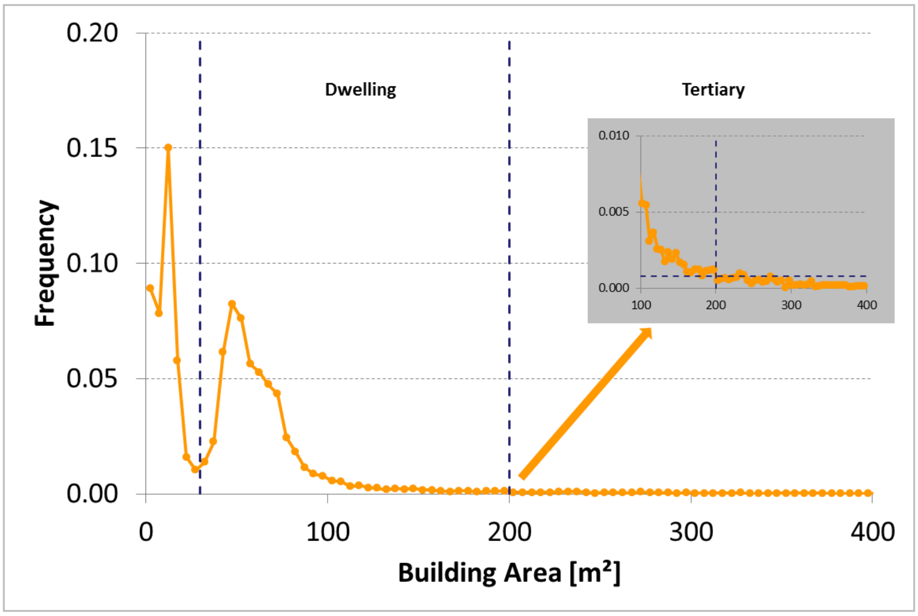


Figure 12-1: Building area frequency diagram for CZ 70 Harrow.

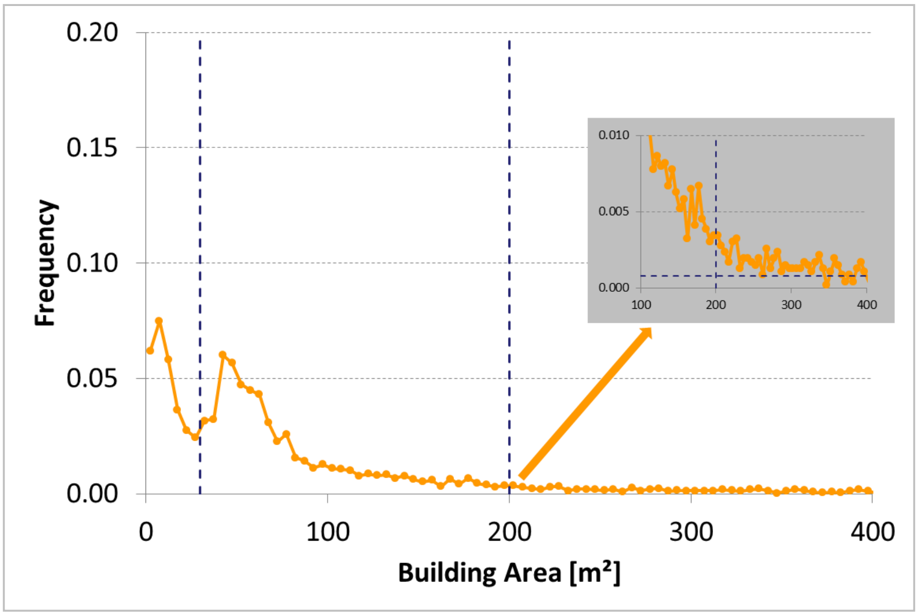


Figure 12-2: Building area frequency diagram for CZ 148 Westminster.

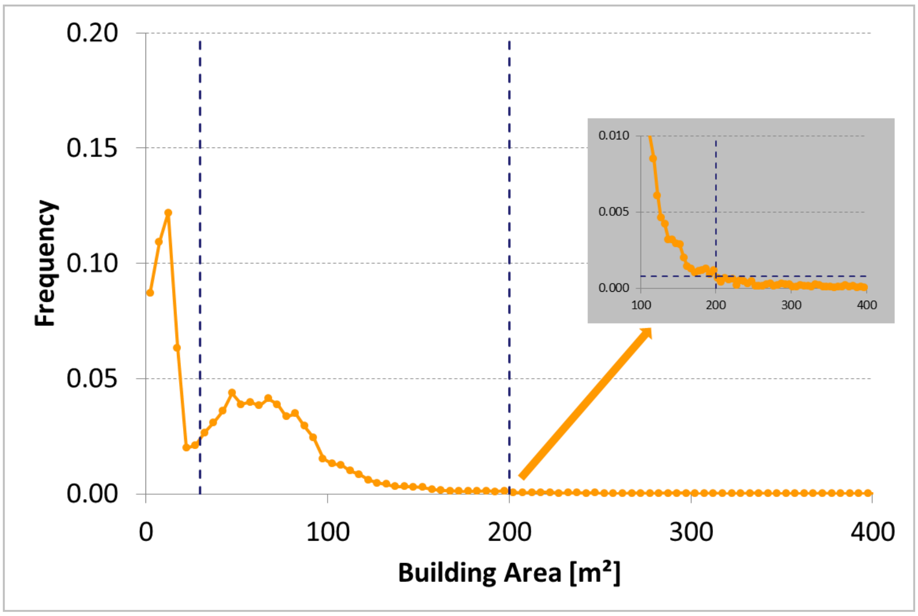
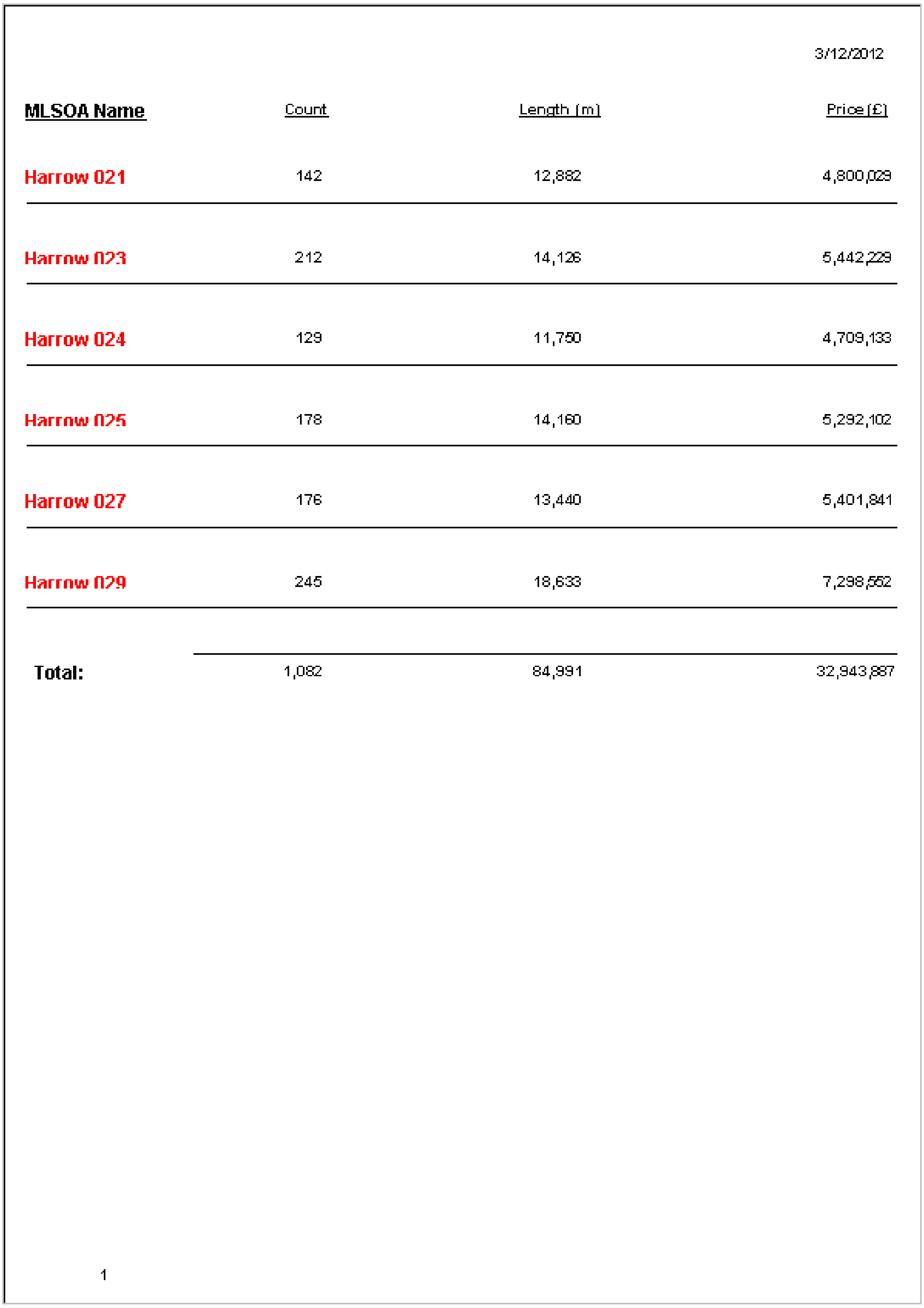


Figure 12-3: Building area frequency diagram for CZ 313Solihull.

12.2 Appendix 2 – Cost Reports

12.2.1 Cost Report 1 - CZ 70 Harrow

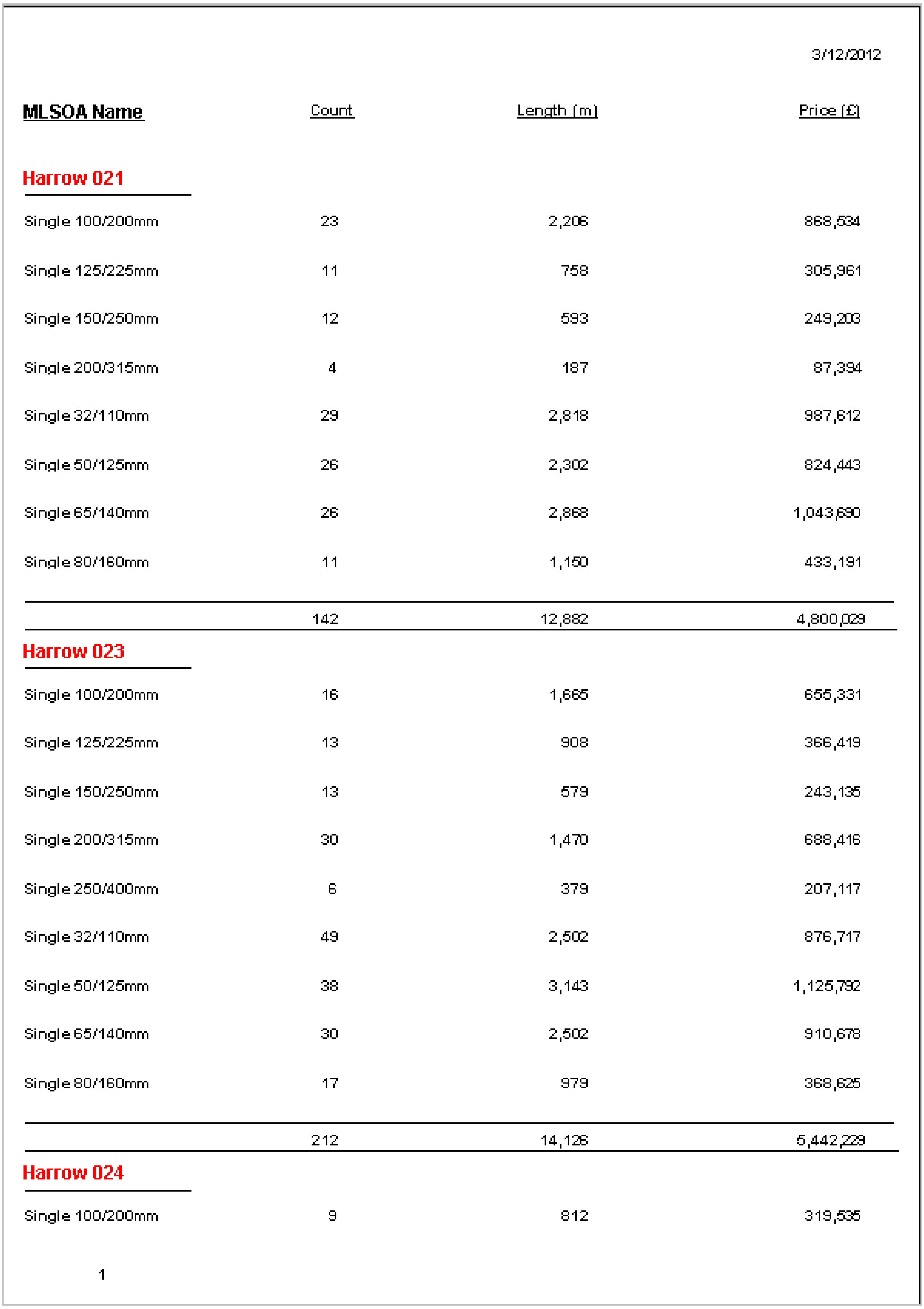


3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Harrow 021	142	12,882	4,800,029
Harrow 023	212	14,126	5,442,229
Harrow 024	129	11,750	4,709,133
Harrow 025	178	14,160	5,292,102
Harrow 027	176	13,440	5,401,841
Harrow 029	245	18,633	7,298,552
Total:	1,082	84,991	32,943,887

1

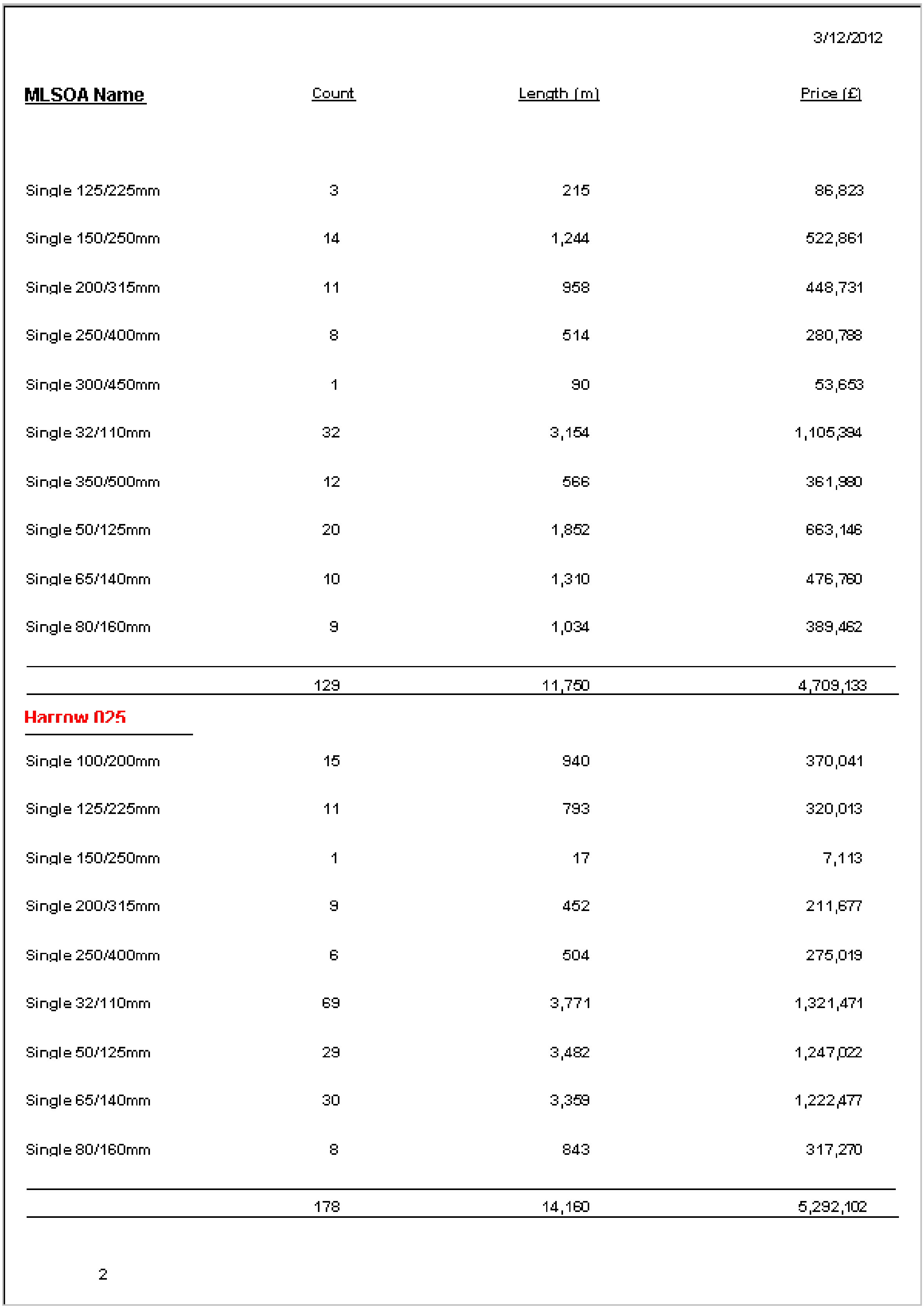
Figure 12-4: Summary cost report for CZ 70 Harrow.



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Harrow 021			
Single 100/200mm	23	2,206	868,534
Single 125/225mm	11	758	305,961
Single 150/250mm	12	593	249,203
Single 200/315mm	4	187	87,394
Single 32/110mm	29	2,818	987,612
Single 50/125mm	26	2,302	824,443
Single 65/140mm	26	2,868	1,043,690
Single 80/160mm	11	1,150	433,191
	142	12,882	4,800,029
Harrow 023			
Single 100/200mm	16	1,665	655,331
Single 125/225mm	13	908	366,419
Single 150/250mm	13	579	243,135
Single 200/315mm	30	1,470	688,416
Single 250/400mm	6	379	207,117
Single 32/110mm	49	2,502	876,717
Single 50/125mm	38	3,143	1,125,792
Single 65/140mm	30	2,502	910,678
Single 80/160mm	17	979	368,625
	212	14,126	5,442,229
Harrow 024			
Single 100/200mm	9	812	319,535

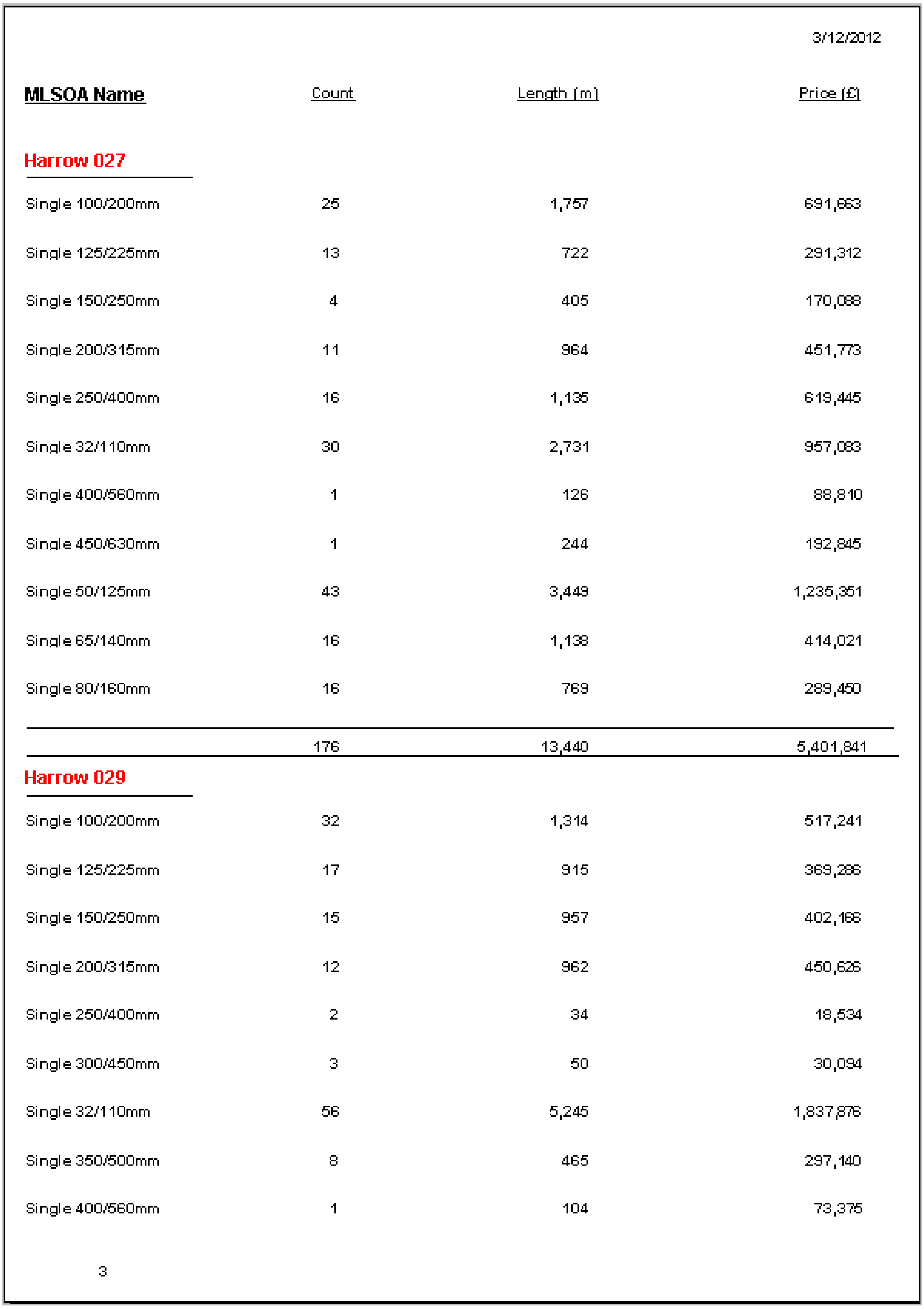
1



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Single 125/225mm	3	215	86,823
Single 150/250mm	14	1,244	522,861
Single 200/315mm	11	958	448,731
Single 250/400mm	8	514	280,788
Single 300/450mm	1	90	53,653
Single 32/110mm	32	3,154	1,105,394
Single 350/500mm	12	566	361,980
Single 50/125mm	20	1,852	663,146
Single 65/140mm	10	1,310	476,760
Single 80/160mm	9	1,034	389,462
	129	11,750	4,709,133
Harrow 025			
Single 100/200mm	15	940	370,041
Single 125/225mm	11	793	320,013
Single 150/250mm	1	17	7,113
Single 200/315mm	9	452	211,677
Single 250/400mm	6	504	275,019
Single 32/110mm	69	3,771	1,321,471
Single 50/125mm	29	3,482	1,247,022
Single 65/140mm	30	3,359	1,222,477
Single 80/160mm	8	843	317,270
	178	14,160	5,292,102

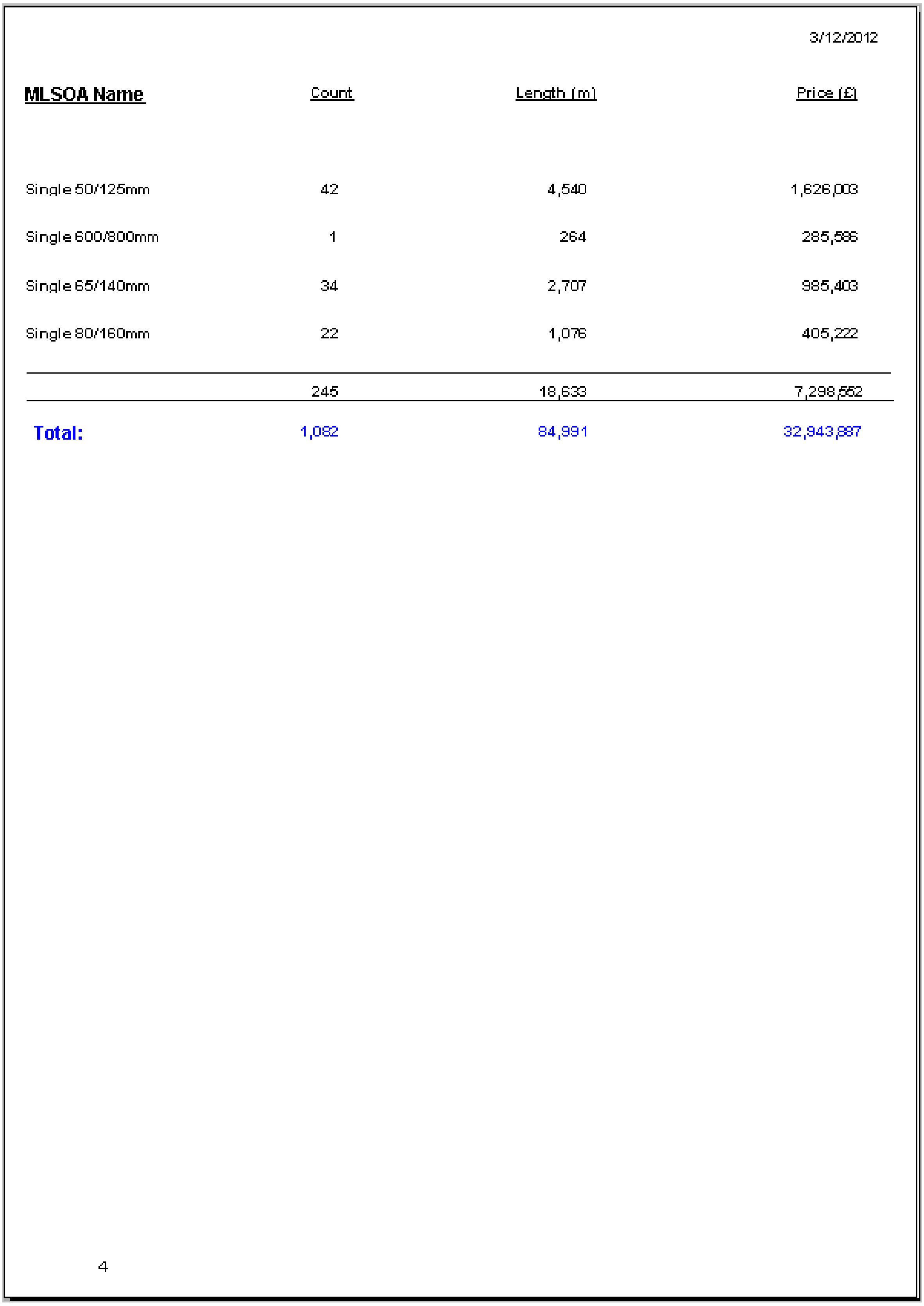
2



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Harrow 027			
Single 100/200mm	25	1,757	691,663
Single 125/225mm	13	722	291,312
Single 150/250mm	4	405	170,088
Single 200/315mm	11	964	451,773
Single 250/400mm	16	1,135	619,445
Single 32/110mm	30	2,731	957,083
Single 400/560mm	1	126	88,810
Single 450/630mm	1	244	192,845
Single 50/125mm	43	3,449	1,235,351
Single 65/140mm	16	1,138	414,021
Single 80/160mm	16	769	289,450
	176	13,440	5,401,841
Harrow 029			
Single 100/200mm	32	1,314	517,241
Single 125/225mm	17	915	369,286
Single 150/250mm	15	957	402,166
Single 200/315mm	12	962	450,626
Single 250/400mm	2	34	18,534
Single 300/450mm	3	50	30,094
Single 32/110mm	56	5,245	1,837,876
Single 350/500mm	8	465	297,140
Single 400/560mm	1	104	73,375

3



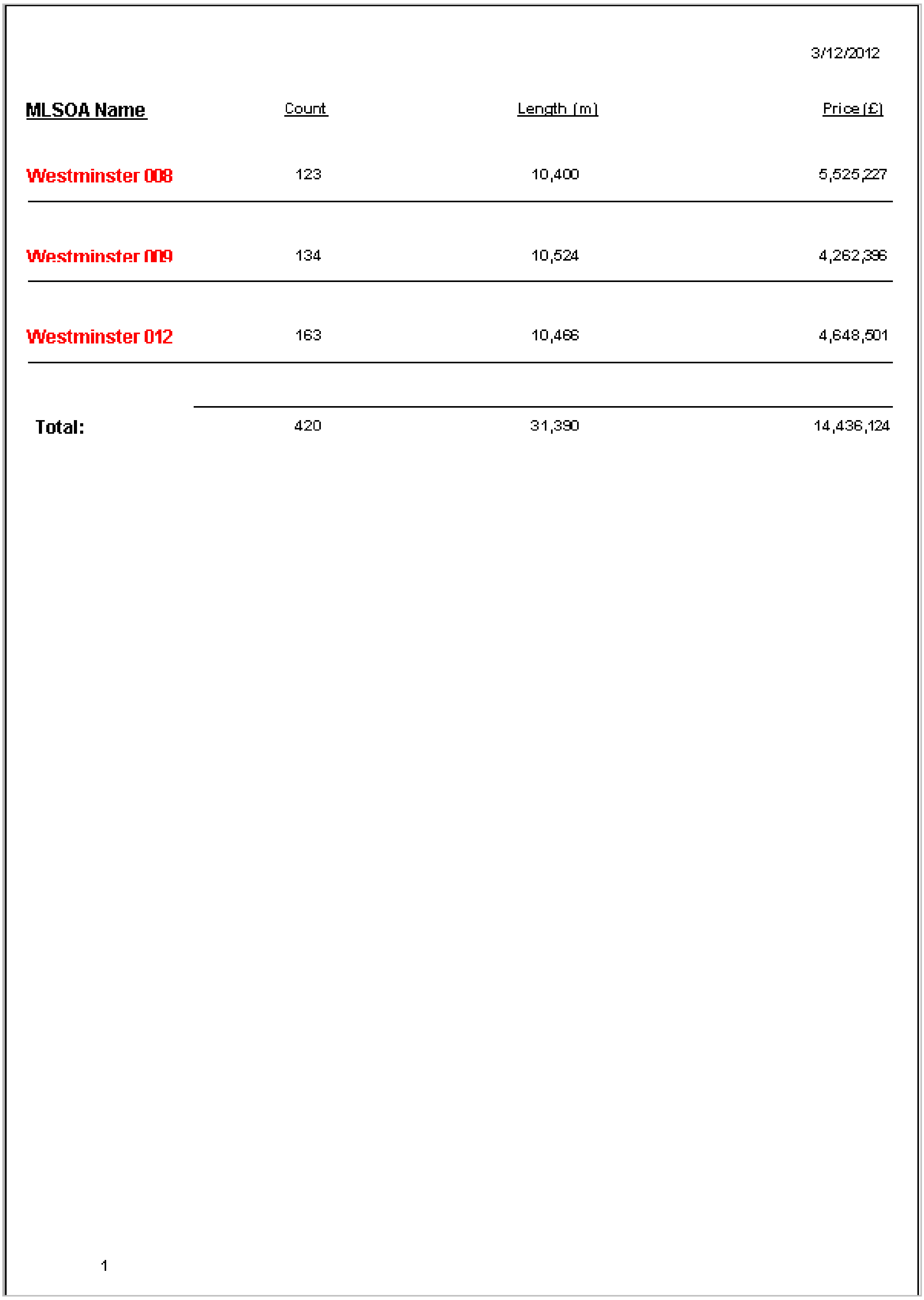
3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Single 50/125mm	42	4,540	1,626,003
Single 600/800mm	1	264	285,586
Single 65/140mm	34	2,707	985,403
Single 80/160mm	22	1,076	405,222
	245	18,633	7,298,552
Total:	1,082	84,991	32,943,887

4

Figure 12-5: Detailed cost report for CZ 70 Harrow.

12.2.2 Cost Report 2 - CZ 148 Westminster

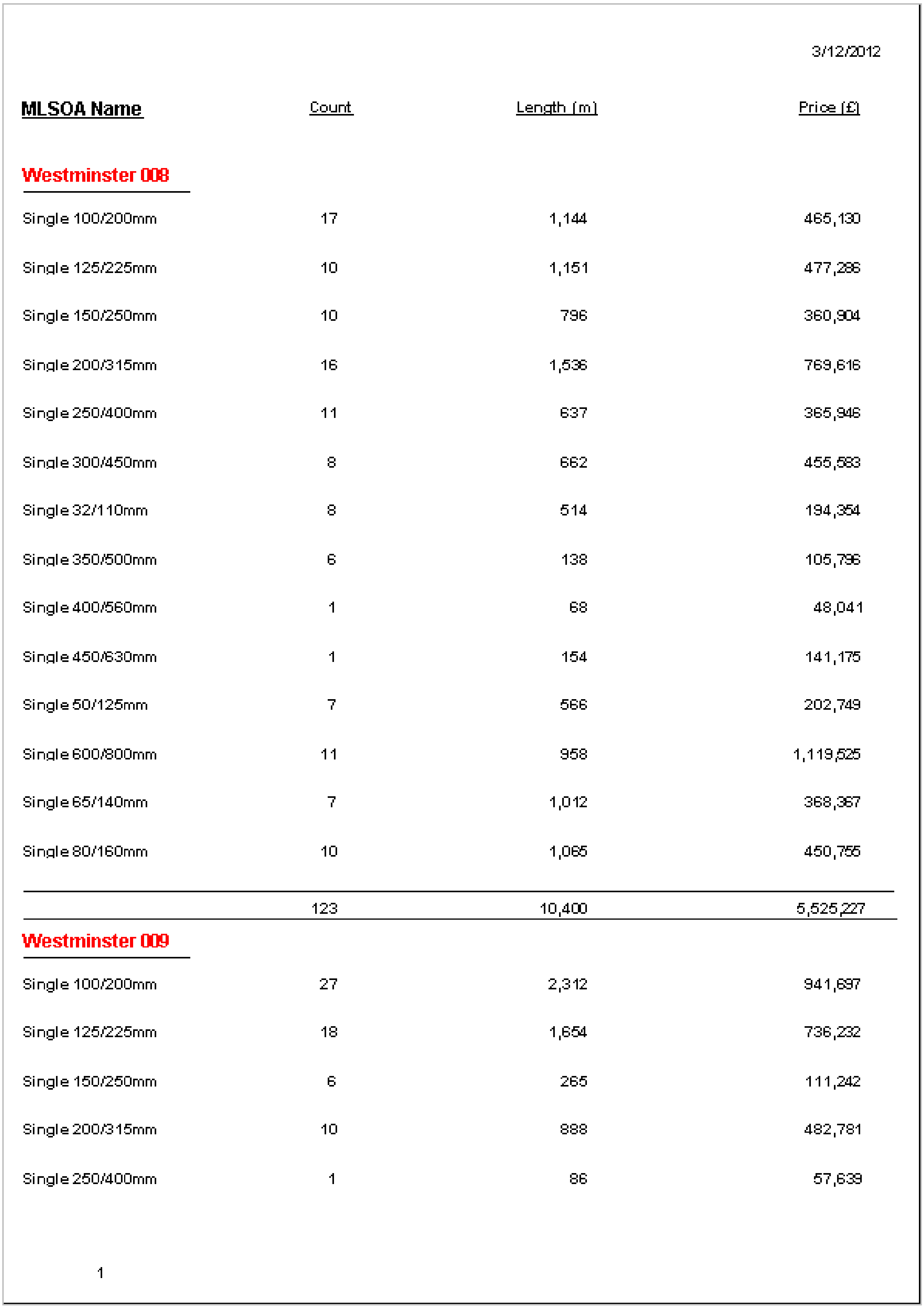


3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Westminster 008	123	10,400	5,525,227
Westminster 009	134	10,524	4,262,396
Westminster 012	163	10,466	4,648,501
Total:	420	31,390	14,436,124

1

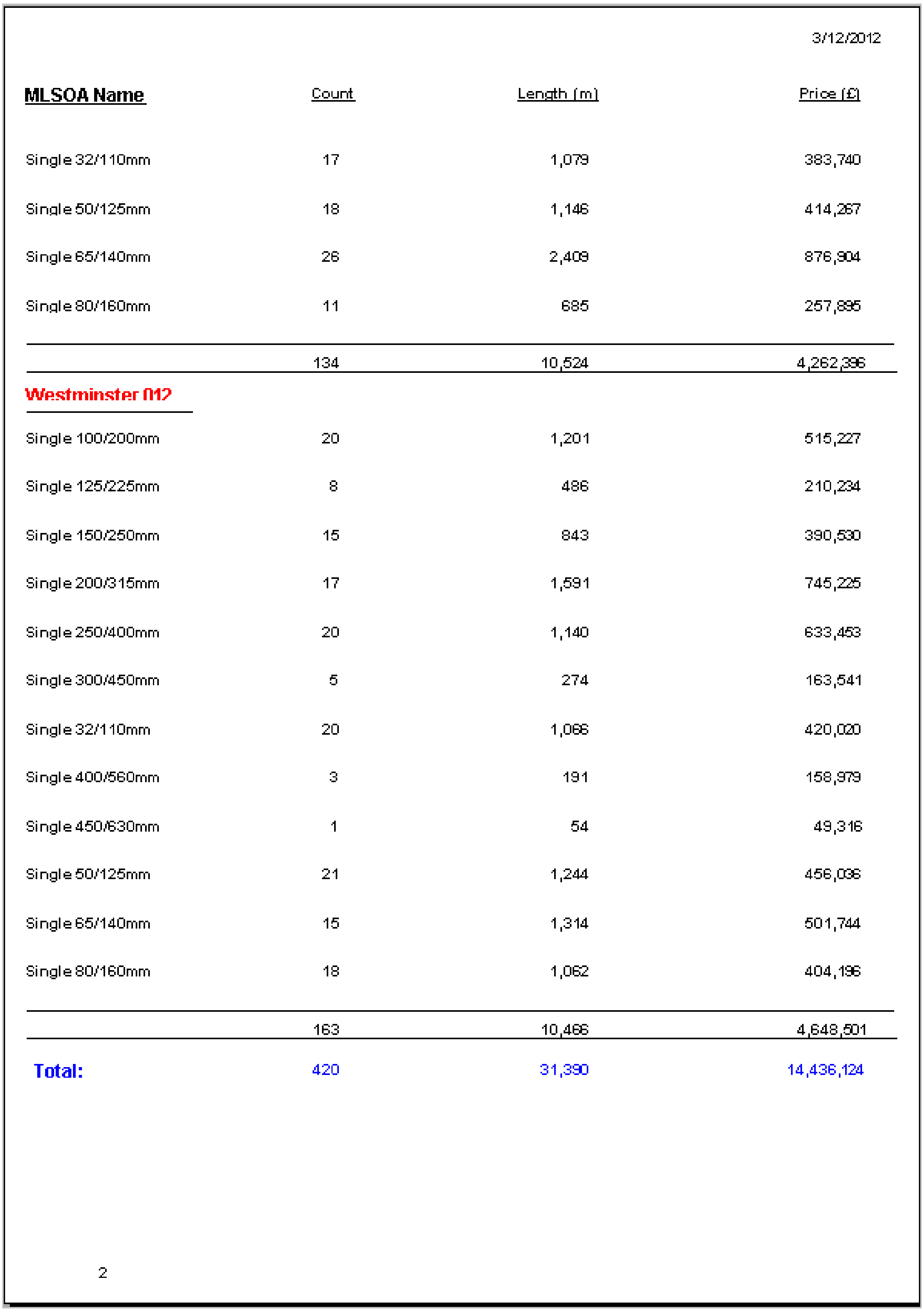
Figure 12-6: Summary cost report for CZ 148 Westminster.



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Westminster 008			
Single 100/200mm	17	1,144	465,130
Single 125/225mm	10	1,151	477,286
Single 150/250mm	10	796	360,904
Single 200/315mm	16	1,536	769,616
Single 250/400mm	11	637	365,946
Single 300/450mm	8	662	455,583
Single 32/110mm	8	514	194,354
Single 350/500mm	6	138	105,796
Single 400/560mm	1	68	48,041
Single 450/630mm	1	154	141,175
Single 50/125mm	7	566	202,749
Single 600/800mm	11	958	1,119,525
Single 65/140mm	7	1,012	368,367
Single 80/160mm	10	1,065	450,755
	123	10,400	5,525,227
Westminster 009			
Single 100/200mm	27	2,312	941,697
Single 125/225mm	18	1,654	736,232
Single 150/250mm	6	265	111,242
Single 200/315mm	10	888	482,781
Single 250/400mm	1	86	57,639

1



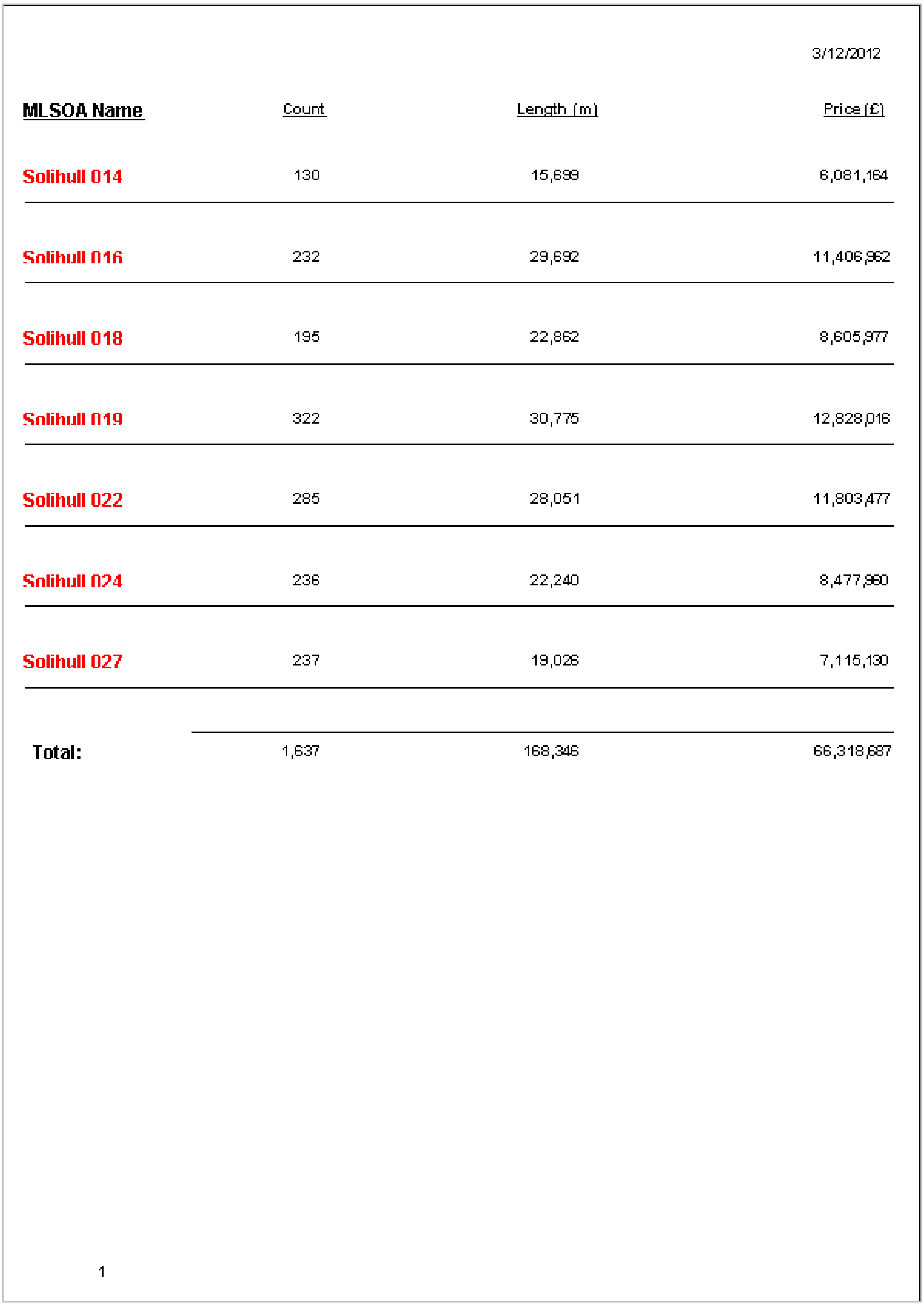
3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Single 32/110mm	17	1,079	383,740
Single 50/125mm	18	1,146	414,267
Single 65/140mm	26	2,409	876,904
Single 80/160mm	11	685	257,895
	134	10,524	4,262,396
Westminster 012			
Single 100/200mm	20	1,201	515,227
Single 125/225mm	8	486	210,234
Single 150/250mm	15	843	390,530
Single 200/315mm	17	1,591	745,225
Single 250/400mm	20	1,140	633,453
Single 300/450mm	5	274	163,541
Single 32/110mm	20	1,066	420,020
Single 400/560mm	3	191	158,979
Single 450/630mm	1	54	49,316
Single 50/125mm	21	1,244	456,036
Single 65/140mm	15	1,314	501,744
Single 80/160mm	18	1,062	404,196
	163	10,466	4,648,501
Total:	420	31,390	14,436,124

2

Figure 12-7: Detailed cost report for CZ 148 Westminster.

12.2.3 Cost Report 3 - CZ 313 Solihull

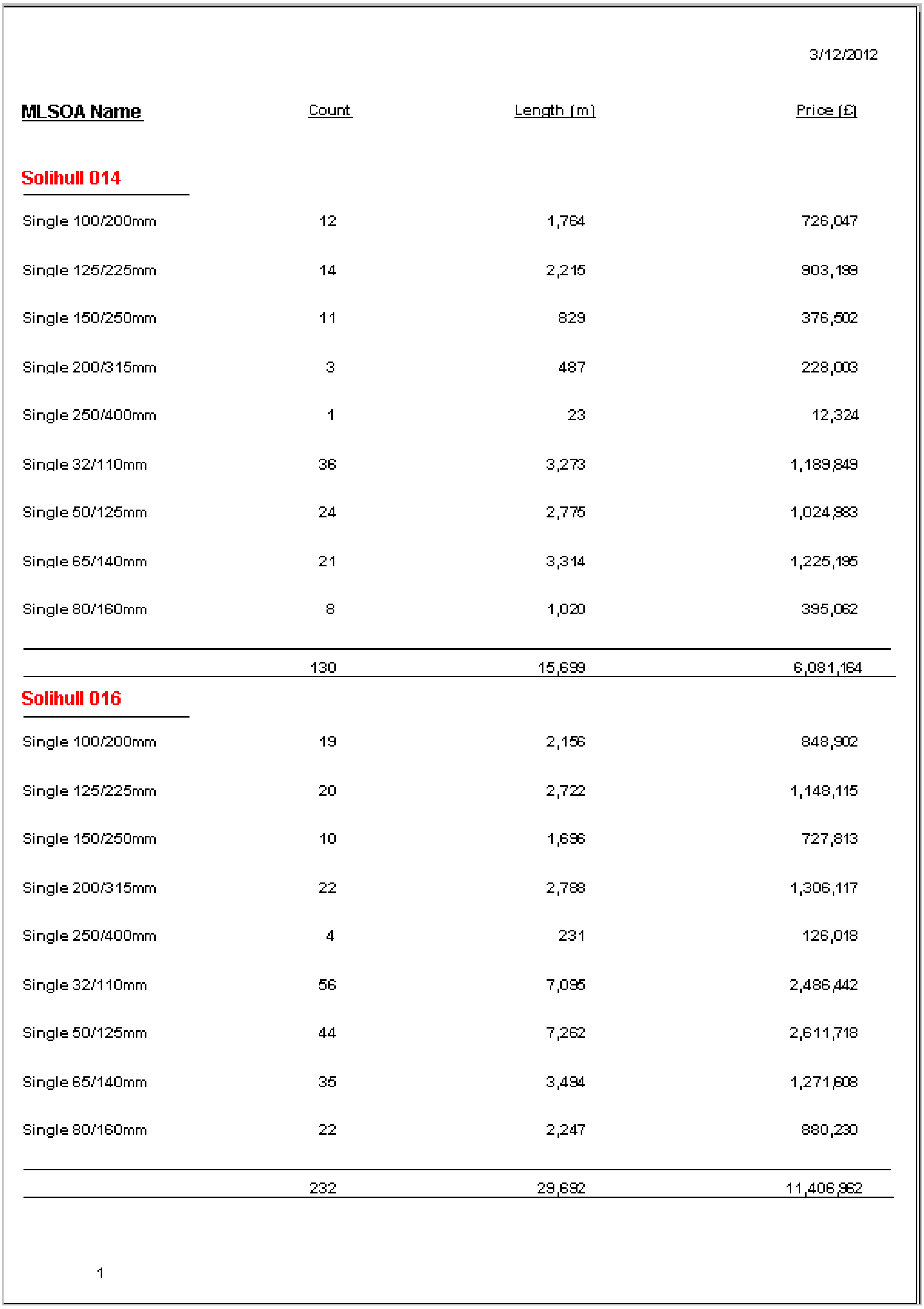


3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Solihull 014	130	15,699	6,081,164
Solihull 016	232	29,692	11,406,962
Solihull 018	195	22,862	8,605,977
Solihull 019	322	30,775	12,828,016
Solihull 022	285	28,051	11,803,477
Solihull 024	236	22,240	8,477,960
Solihull 027	237	19,026	7,115,130
Total:	1,637	168,346	66,318,687

1

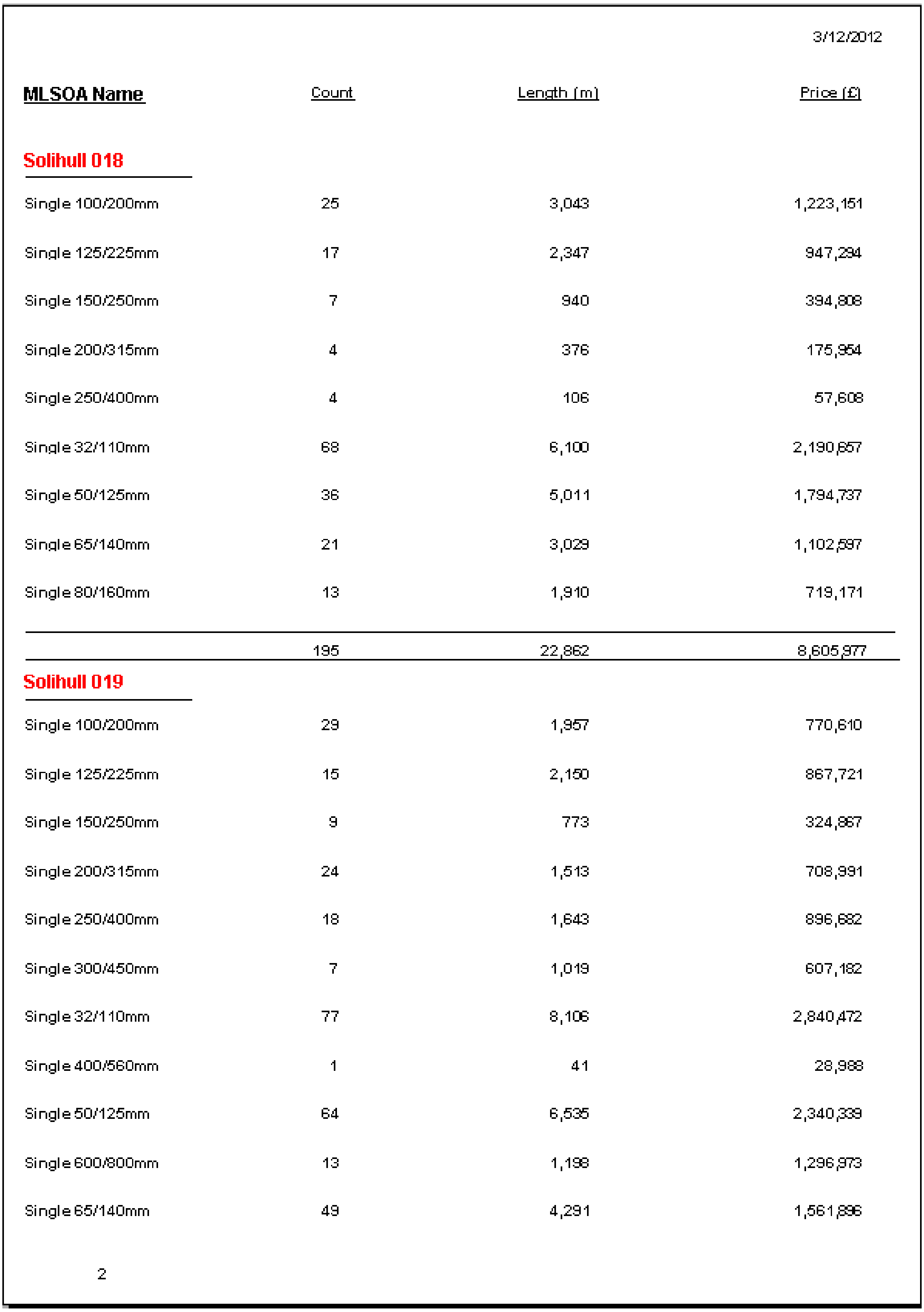
Figure 12-8: Summary cost report for CZ 148 Westminster.



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Solihull 014			
Single 100/200mm	12	1,764	726,047
Single 125/225mm	14	2,215	903,199
Single 150/250mm	11	829	376,502
Single 200/315mm	3	487	228,003
Single 250/400mm	1	23	12,324
Single 32/110mm	36	3,273	1,189,849
Single 50/125mm	24	2,775	1,024,983
Single 65/140mm	21	3,314	1,225,195
Single 80/160mm	8	1,020	395,062
	130	15,699	6,081,164
Solihull 016			
Single 100/200mm	19	2,156	848,902
Single 125/225mm	20	2,722	1,148,115
Single 150/250mm	10	1,696	727,813
Single 200/315mm	22	2,788	1,306,117
Single 250/400mm	4	231	126,018
Single 32/110mm	56	7,095	2,486,442
Single 50/125mm	44	7,262	2,611,718
Single 65/140mm	35	3,494	1,271,608
Single 80/160mm	22	2,247	880,230
	232	29,692	11,406,962

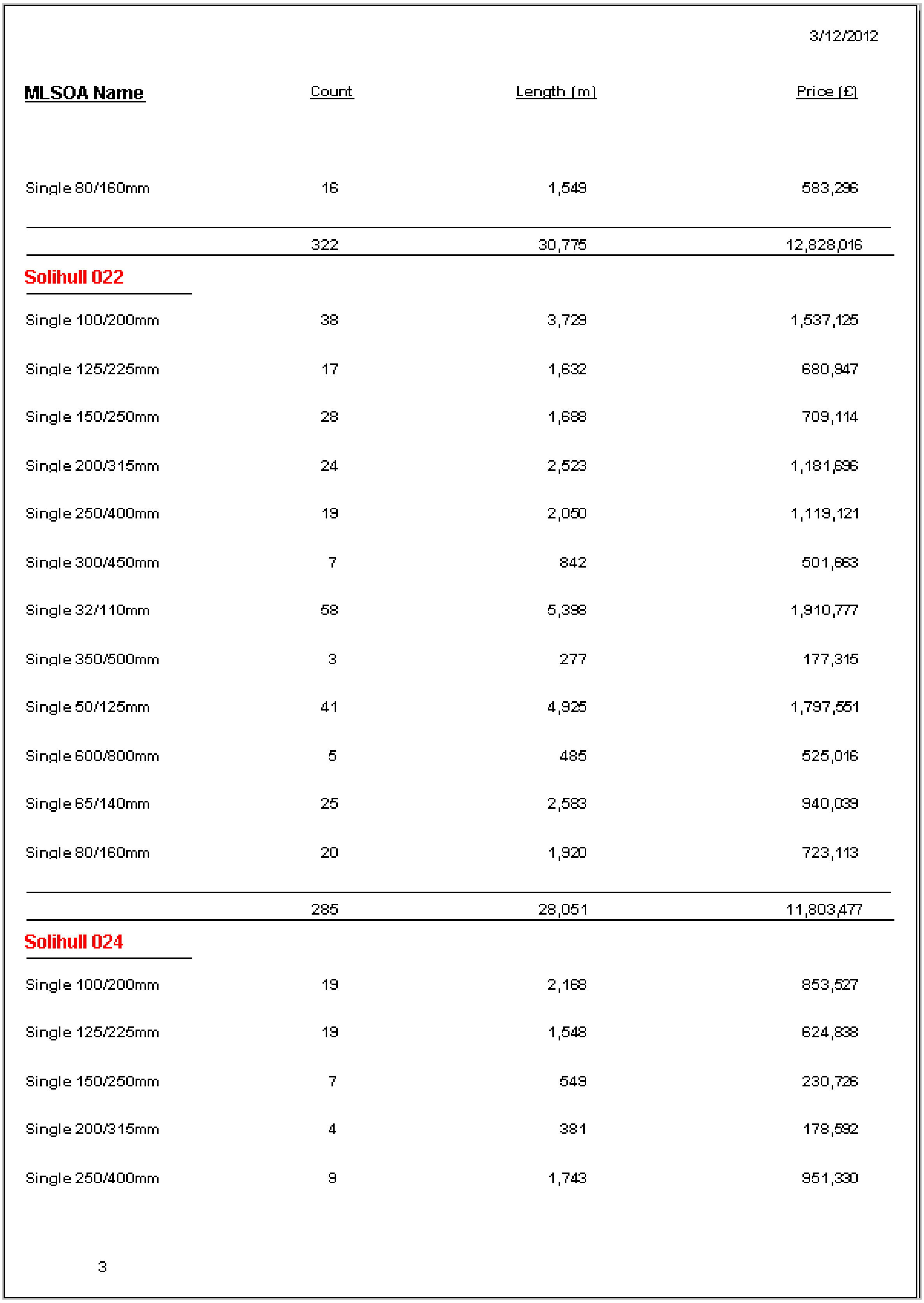
1



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Solihull 018			
Single 100/200mm	25	3,043	1,223,151
Single 125/225mm	17	2,347	947,294
Single 150/250mm	7	940	394,808
Single 200/315mm	4	376	175,954
Single 250/400mm	4	106	57,608
Single 32/110mm	68	6,100	2,190,657
Single 50/125mm	36	5,011	1,794,737
Single 65/140mm	21	3,029	1,102,597
Single 80/160mm	13	1,910	719,171
	195	22,862	8,605,977
Solihull 019			
Single 100/200mm	29	1,957	770,610
Single 125/225mm	15	2,150	867,721
Single 150/250mm	9	773	324,867
Single 200/315mm	24	1,513	708,991
Single 250/400mm	18	1,643	896,682
Single 300/450mm	7	1,019	607,182
Single 32/110mm	77	8,106	2,840,472
Single 400/560mm	1	41	28,988
Single 50/125mm	64	6,535	2,340,339
Single 600/800mm	13	1,198	1,296,973
Single 65/140mm	49	4,291	1,561,896

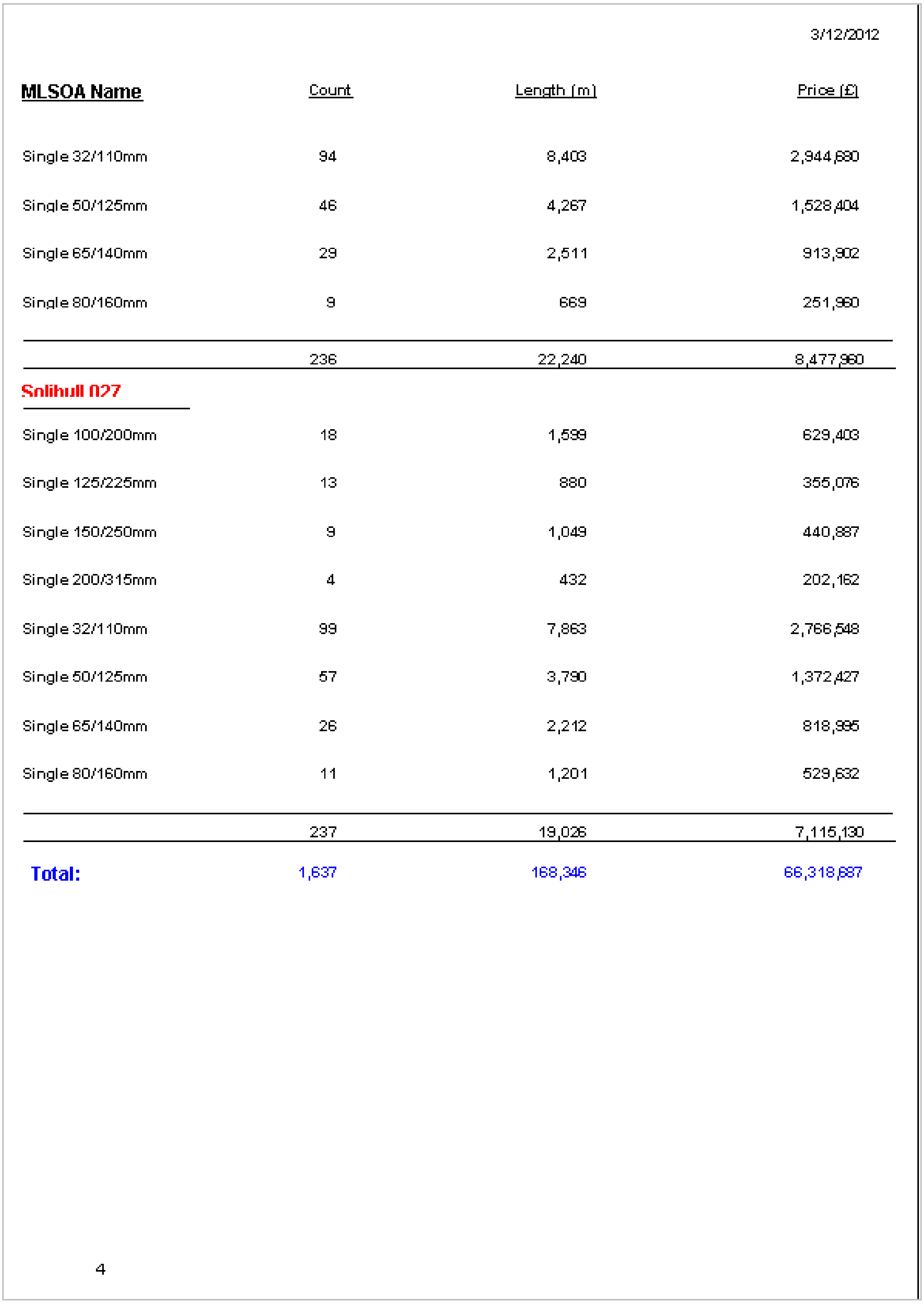
2



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Single 80/160mm	16	1,549	583,296
	322	30,775	12,828,016
Solihull 022			
Single 100/200mm	38	3,729	1,537,125
Single 125/225mm	17	1,632	680,947
Single 150/250mm	28	1,688	709,114
Single 200/315mm	24	2,523	1,181,696
Single 250/400mm	19	2,050	1,119,121
Single 300/450mm	7	842	501,663
Single 32/110mm	58	5,398	1,910,777
Single 350/500mm	3	277	177,315
Single 50/125mm	41	4,925	1,797,551
Single 600/800mm	5	485	525,016
Single 65/140mm	25	2,583	940,039
Single 80/160mm	20	1,920	723,113
	285	28,051	11,803,477
Solihull 024			
Single 100/200mm	19	2,168	853,527
Single 125/225mm	19	1,548	624,838
Single 150/250mm	7	549	230,726
Single 200/315mm	4	381	178,592
Single 250/400mm	9	1,743	951,330

3



3/12/2012

MLSOA Name	Count	Length (m)	Price (£)
Single 32/110mm	94	8,403	2,944,680
Single 50/125mm	46	4,267	1,528,404
Single 65/140mm	29	2,511	913,902
Single 80/160mm	9	669	251,960
	236	22,240	8,477,960
Solihull 027			
Single 100/200mm	18	1,599	629,403
Single 125/225mm	13	880	355,076
Single 150/250mm	9	1,049	440,887
Single 200/315mm	4	432	202,162
Single 32/110mm	99	7,863	2,766,548
Single 50/125mm	57	3,790	1,372,427
Single 65/140mm	26	2,212	818,395
Single 80/160mm	11	1,201	529,632
	237	19,026	7,115,130
Total:	1,637	168,346	66,318,687

4

Figure 12-9: Detailed cost report for CZ 313 Solihull.

12.3 Appendix 3 – Heat Demands

This data is part of an excel file about the CZs provided to the University of Manchester and attached to Ref. 3.

12.3.1 Heat Demands - Winter

Heat Loads in kWh			**Harrow 023**	**Solihull 022**	**Westminster 012**
Winter	Weekday	0:00 - 04:59	3.26E+04	52700	5.67E+04
Winter	Weekday	5:00 - 6:59	6.47E+04	100000	9.36E+04
Winter	Weekday	7:00 - 9:59	6.33E+04	99500	9.26E+04
Winter	Weekday	10:00 - 16:59	5.31E+04	84600	7.48E+04
Winter	Weekday	17:00 - 18:59	5.83E+04	92000	7.21E+04
Winter	Weekday	19:00 - 21:59	5.69E+04	87500	6.94E+04
Winter	Weekday	22:00 - 23:59	3.58E+04	54400	5.36E+04
Winter	Weekend	0:00 - 04:59	3.35E+04	52600	5.42E+04
Winter	Weekend	5:00 - 6:59	6.52E+04	100100	8.29E+04
Winter	Weekend	7:00 - 9:59	6.36E+04	98600	8.02E+04
Winter	Weekend	10:00 - 16:59	5.45E+04	85100	7.01E+04
Winter	Weekend	17:00 - 21:59	5.98E+04	92200	7.33E+04
Winter	Weekend	22:00 - 23:59	3.78E+04	56500	5.79E+04
Winter		**Peak**	**1.04E+05**	**153300**	**1.45E+05**
Winter		**Base**	**6.60E+03**	**13100**	**1.39E+04**
Winter		**Peak-Base**	**9.71E+04**	**140200**	**1.31E+05**
Winter		**Average**	**5.09E+04**	**79800**	**7.12E+04**
Winter	**Weekday**	**Days**	**87**	**87**	**87**
Winter	**Weekend**	**Days**	**34**	**34**	**34**

Table 12-2: Winter heat demand details for all three CZs.

12.3.2 Heat Demands - Transition

Heat Loads in kWh			**Harrow 023**	**Solihull 022**	**Westminster 012**
Transition	Weekday	0:00 - 04:59	1.78E+04	31400	3.21E+04
Transition	Weekday	5:00 - 6:59	4.11E+04	70000	5.90E+04
Transition	Weekday	7:00 - 9:59	3.95E+04	68000	5.54E+04
Transition	Weekday	10:00 - 16:59	3.06E+04	53200	4.22E+04
Transition	Weekday	17:00 - 18:59	3.34E+04	59100	4.05E+04
Transition	Weekday	19:00 - 21:59	3.44E+04	58400	4.04E+04
Transition	Weekday	22:00 - 23:59	2.08E+04	33700	3.08E+04
Transition	Weekend	0:00 - 04:59	1.75E+04	30600	2.91E+04
Transition	Weekend	5:00 - 6:59	4.00E+04	66800	4.90E+04
Transition	Weekend	7:00 - 9:59	3.85E+04	65200	4.66E+04
Transition	Weekend	10:00 - 16:59	3.02E+04	52200	3.82E+04
Transition	Weekend	17:00 - 21:59	3.41E+04	58600	4.01E+04
Transition	Weekend	22:00 - 23:59	2.12E+04	34400	3.22E+04
Transition		**Peak**	**7.76E+04**	**119000**	**1.12E+05**
Transition		**Base**	**5.80E+03**	**12000**	**1.22E+04**
Transition		**Peak-Base**	**7.18E+04**	**107000**	**9.98E+04**
Transition		**Average**	**2.97E+04**	**51100**	**4.07E+04**
Transition	**Weekday**	**Days**	**86**	**86**	**86**
Transition	**Weekend**	**Days**	**36**	**36**	**36**

Table 12-3: Transition heat demand details for all three CZs.

12.3.3 Heat Demands - Summer

Heat Loads in kWh			Harrow 023	Solihull 022	Westminster 012
Summer	Weekday	0:00 - 04:59	6.50E+03	11300	1.30E+04
Summer	Weekday	5:00 - 6:59	1.90E+04	35200	2.58E+04
Summer	Weekday	7:00 - 9:59	1.76E+04	32400	2.31E+04
Summer	Weekday	10:00 - 16:59	1.24E+04	22300	1.72E+04
Summer	Weekday	17:00 - 18:59	1.26E+04	23300	1.60E+04
Summer	Weekday	19:00 - 21:59	1.38E+04	25000	1.65E+04
Summer	Weekday	22:00 - 23:59	8.40E+03	13800	1.31E+04
Summer	Weekend	0:00 - 04:59	5.60E+03	9500	1.06E+04
Summer	Weekend	5:00 - 6:59	1.70E+04	31300	1.92E+04
Summer	Weekend	7:00 - 9:59	1.59E+04	29100	1.82E+04
Summer	Weekend	10:00 - 16:59	1.12E+04	19800	1.41E+04
Summer	Weekend	17:00 - 21:59	1.21E+04	21800	1.43E+04
Summer	Weekend	22:00 - 23:59	7.70E+03	12600	1.22E+04
Summer		**Peak**	**3.50E+04**	**65000**	**5.26E+04**
Summer		**Base**	**2.80E+03**	**4900**	**7.00E+03**
Summer		**Peak-Base**	**3.22E+04**	**60200**	**4.55E+04**
Summer		**Average**	**1.19E+04**	**21400**	**1.64E+04**
Summer	**Weekday**	**Days**	**88**	**88**	**88**
Summer	**Weekend**	**Days**	**34**	**34**	**34**

Table 12-4: Summer heat demand details for all three CZs.

12.4 Appendix 4 – Simplified Algorithm

Zone type	Annual heat demand (£, 2010)
Low density (LD) < 0.35 GWh/hectare	HeatDemand (GWh/y) x (**725.3** m/GWh x 512.5 £/m + **556.6** m/GWh x 132 £/m) + Number HH x 1,750 £/meter + Number Tertiary x 4,800 £/meter
High density (HD) > 0.35 GWh/hectare, < 0.04 GWh/meter	HeatDemand (GWh/y) x (**543.8** m/GWh x 512.5 £/m + **360.9** m/GWh x 132 £/m) + NumberHH x 1,750 £/meter + NumberTertiary x 4,800 £/meter
High density, high intensity (HD/HI) > 0.35 GWh/hectare, > 0.04 GWh/meter	HeatDemand (GWh/y) x (**482.2** m/GWh x 512.5 £/m + **381.3** m/GWh x 132 £/m) + NumberHH x 1,750 £/meter + NumberTertiary x 4,800 £/meter

Table 12-5: Simple algorithm for estimating capital cost of district heating network NumberHH: number of households; meter: gas meter; NumberTertiary: number of tertiary meters