Technical Seminar

Developments in Academic Research, Standards & Accreditation

“Borehole design charts and thermal conductivity”

Robin Curtis, Technical Director, Mimer Energy Ltd

Homerton College – Cambridge – 16th November 2011

MIMER
NEXT GENERATION ENERGY

Robin Curtis

Technical Director – Mimer Energy Ltd
Director – GeoScience Ltd

(ex EarthEnergy Ltd)

Credits and thanks to:

Tom Pine / Carl von Savageri - Mimer

Chris Wickins - DECC

Other installers and manufacturers

Members of the MCS Heat Pump Working Group

The Certification Mark for Onsite
Sustainable Energy Technologies

MCS 022: GROUND HEAT EXCHANGER LOOK-UP TABLES

SUPPLEMENTARY MATERIAL TO MIS 3005

DRAFT Issue 1.0

What’s the problem ?!

Types of Heat Pump Systems

1) Ones that don’t work
2) Ones that “work”
3) Ones that work &
    - Save significant carbon
    - Deliver significant renewables
    - At reasonable running cost

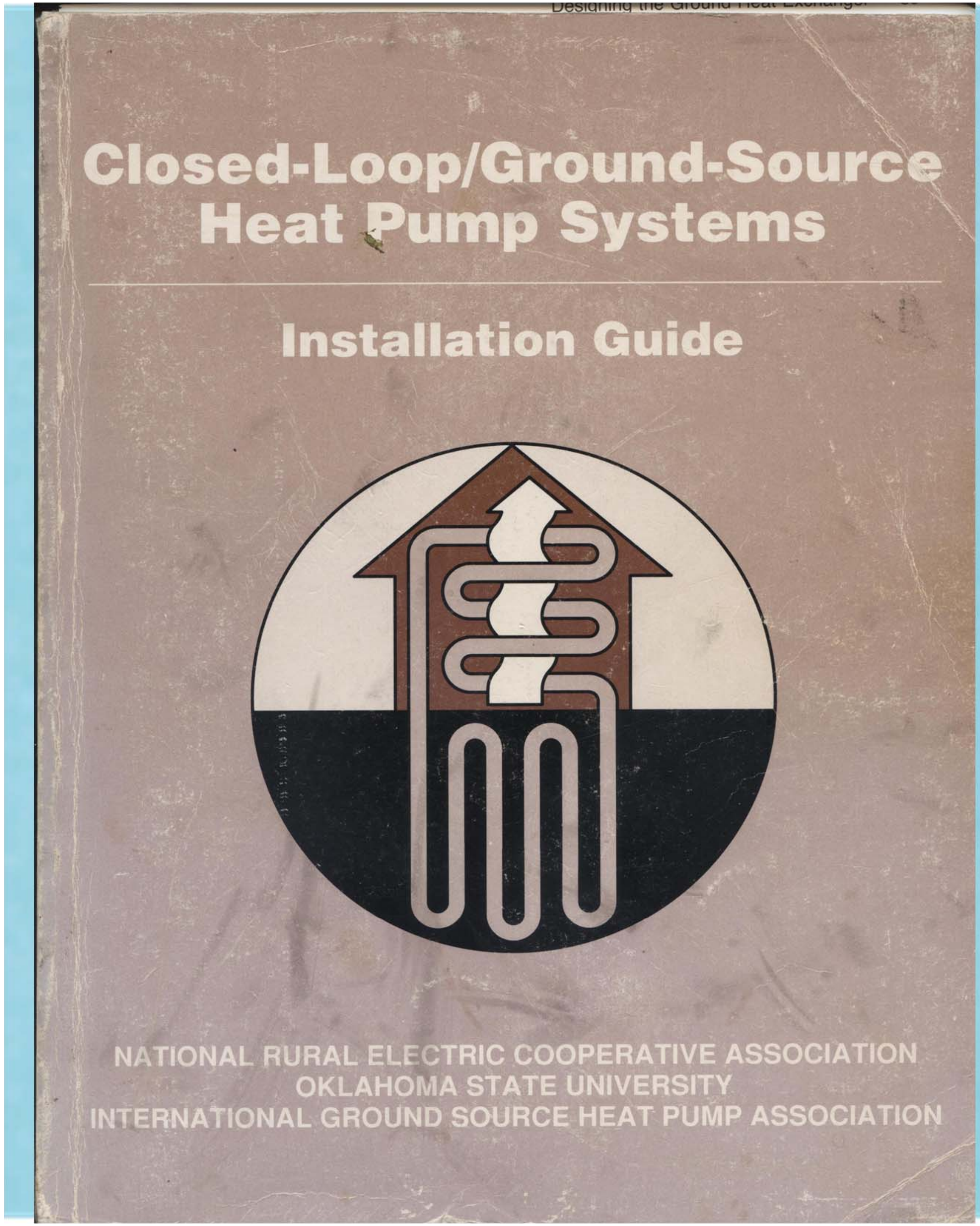
(GS)HP MCS Standards

Ground related issues

Need a robust method
for domestic and small commercial
(heating +DHW)systems.

Provide an (auditable) Backstop

(as per IGSHPA ?)



Closed-Loop/Ground-Source
Heat Pump Systems

Installation Guide

NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION
OKLAHOMA STATE UNIVERSITY
INTERNATIONAL GROUND SOURCE HEAT PUMP ASSOCIATION

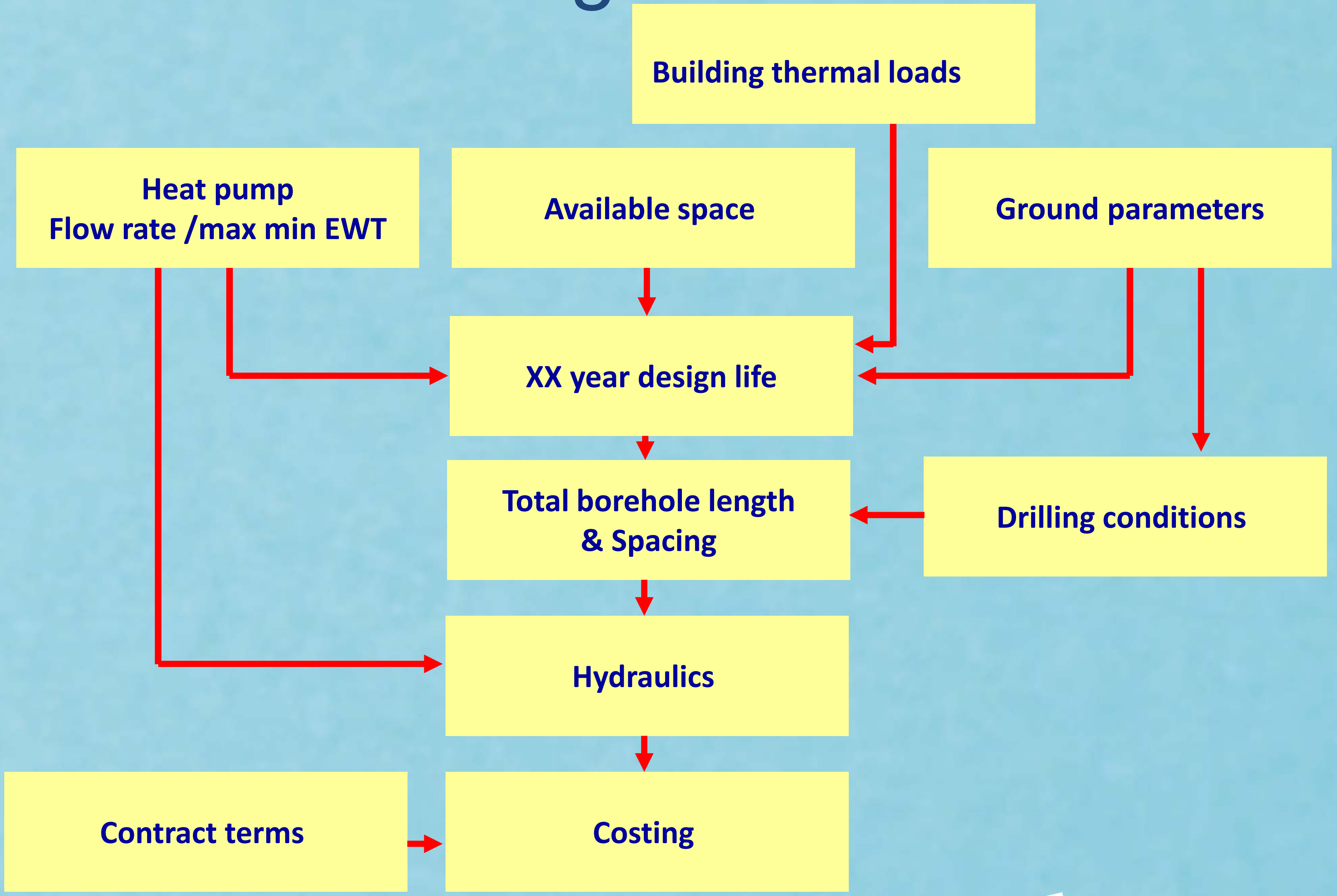
Impressive achievement……

Covers whole of US…….

Jim Bose comments…..

Let’s not get too clever .

Design Process



Building thermal loads

Heat pump
Flow rate /max min EWT

Available space

Ground parameters

XX year design life

Total borehole length
& Spacing

Drilling conditions

Hydraulics

Contract terms

Costing

HP size determined by:

House size

House construction

Location (climate)

Load side flow temperature

Ground loop size
determined by:
HP size (kW)
Ground conditions
Annual demand (kWh)
Climate (ground temperature)

Process:

Determine worst day heat loss
(100% rule)

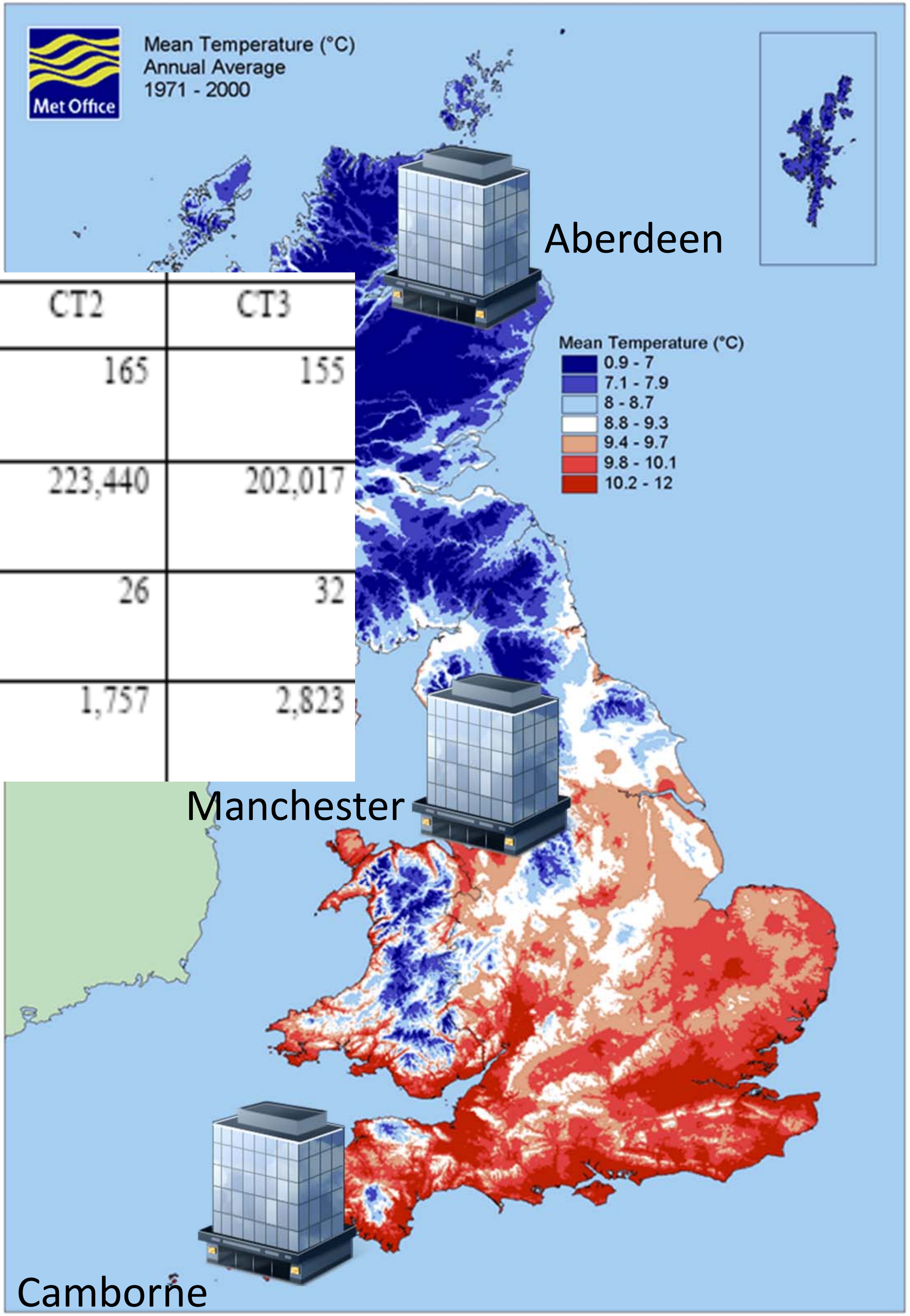
Determine emitter system → SPF

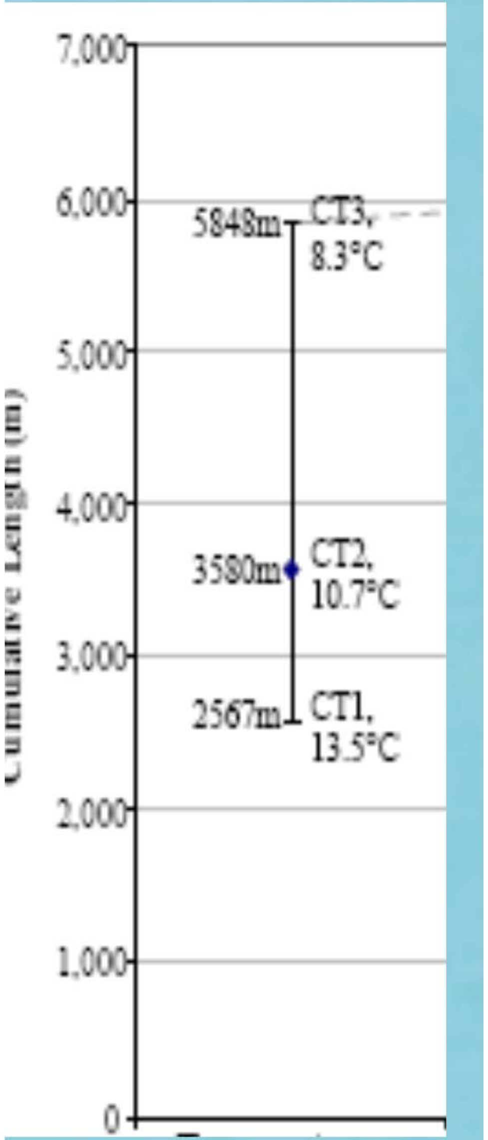
Determine power (kW) > HP sizing

and (for a GSHP) > energy (kWh) to be extracted from ground

Size ground loop -

Climate Type	CT1	CT2	CT3
Heating Peak Capacity (kW)	192	165	155
Heating Energy (kWh)	268,099	223,440	202,017
Cooling Peak Capacity (kW)	18	26	32
Cooling Energy (kWh)	535	1,757	2,823

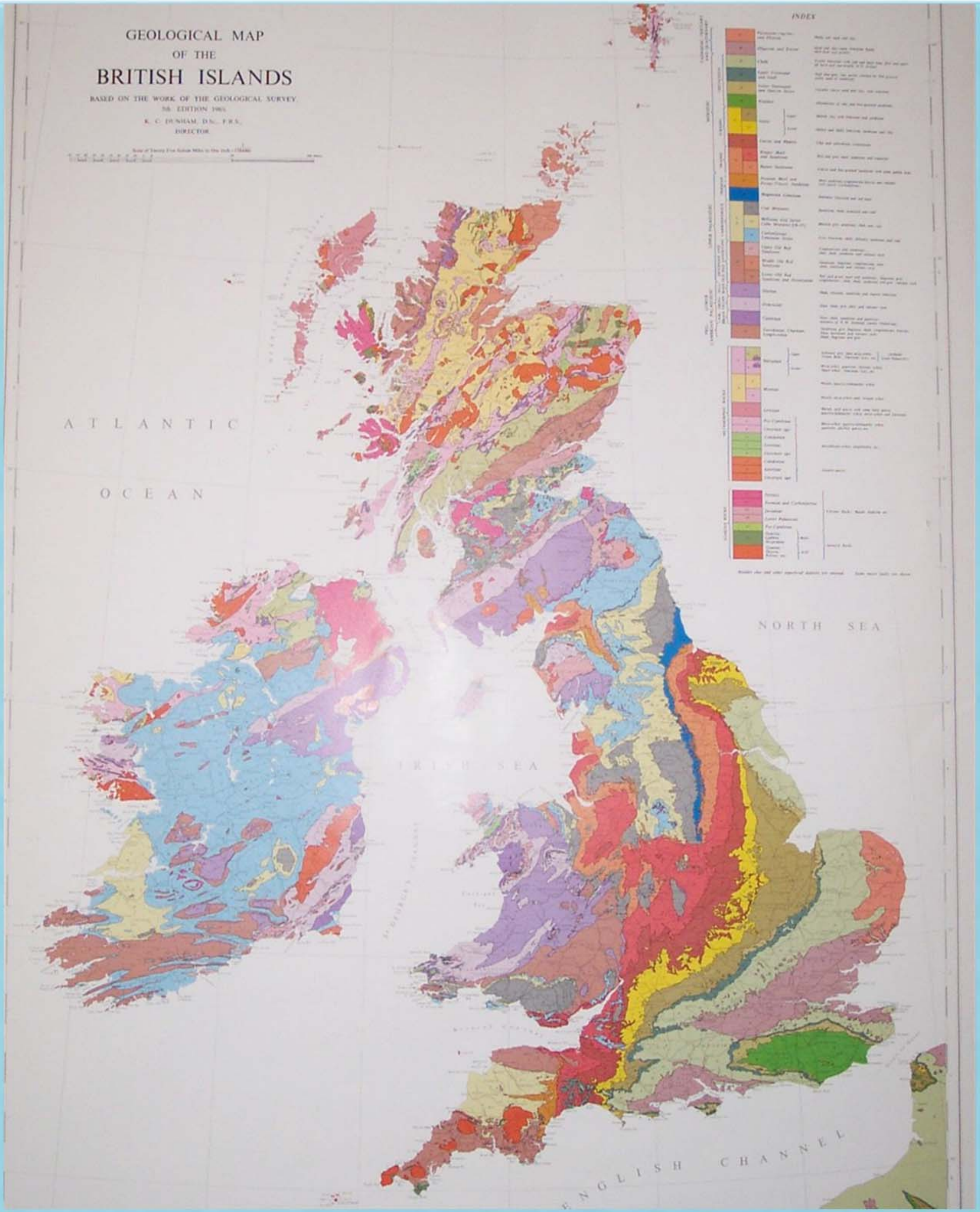




Same Office building in 3 different locations

Cornwall	2,567m (13.5C)
Leeds	3,580m (10.7C)
Aberdeen	5,848m (8.3C)

(from James Dickinson PhD thesis)


GEOLOGICAL MAP
OF THE
BRITISH ISLANDS
BASED ON THE WORK OF THE GEOLOGICAL SURVEY
K. C. DUNHAM, D.Sc., F.R.S.,
DIRECTOR
INDEX
ATLANTIC
OCEAN
NORTH SEA
IRISH SEA
ENGLISH CHANNEL

Concerns with existing practice ?

VDI 4640 issues

Manufacturers’ software issues

Are the UK’s full range of climatic and geological conditions being addressed?
(ASHPs and GSHPs)

Table 2. Possible specific extraction values for borehole heat exchangers

- only heat extraction (heating incl. hot water)
- length of the individual borehole heat exchangers must be between 40 and 100 m
- smallest distance between two borehole heat exchangers must be:
  at least 5 m for borehole heat exchanger lengths of 40 to 50 m
  at least 6 m for borehole heat exchanger lengths of > 50 m to 100 m
- double U-pipes with DN 20, DN 25 or DN 32
  or coaxial probes with a minimum diameter of 60 mm are used as borehole heat exchangers
- not applicably to a larger number of small systems on a limited area

Underground	Specific heat extraction	
	for 1800 h	for 2400 h
General guideline values:		
Poor underground (dry sediment) ($\lambda < 1.5$ W/(m · K))	25 W/m	20 W/m
Normal rocky underground and water saturated sediment ($\lambda < 1.5$–3.0 W/(m · K))	60 W/m	50 W/m
Consolidated rock with high thermal conductivity ($\lambda > 3.0$ W/(m · K))	84 W/m	70 W/m
Individual rocks:		
Gravel, sand, dry	< 25 W/m	< 20 W/m
Gravel, sand, saturated water	65–80 W/m	55–65 W/m
For strong groundwater flow in gravel and sand, for individual systems	80–100 W/m	80–100 W/m
Clay, loam, damp	35–50 W/m	30–40 W/m
Limestone (massif)	55–70 W/m	45–60 W/m
Sandstone	65–80 W/m	55–65 W/m
Siliceous magmatite (e.g. granite)	65–85 W/m	55–70 W/m
Basic magmatite (e.g. basalt)	40–65 W/m	35–55 W/m
Gneiss	70–85 W/m	60–70 W/m
The values can vary significantly due to rock fabric such as crevices, foliation, weathering, etc.		

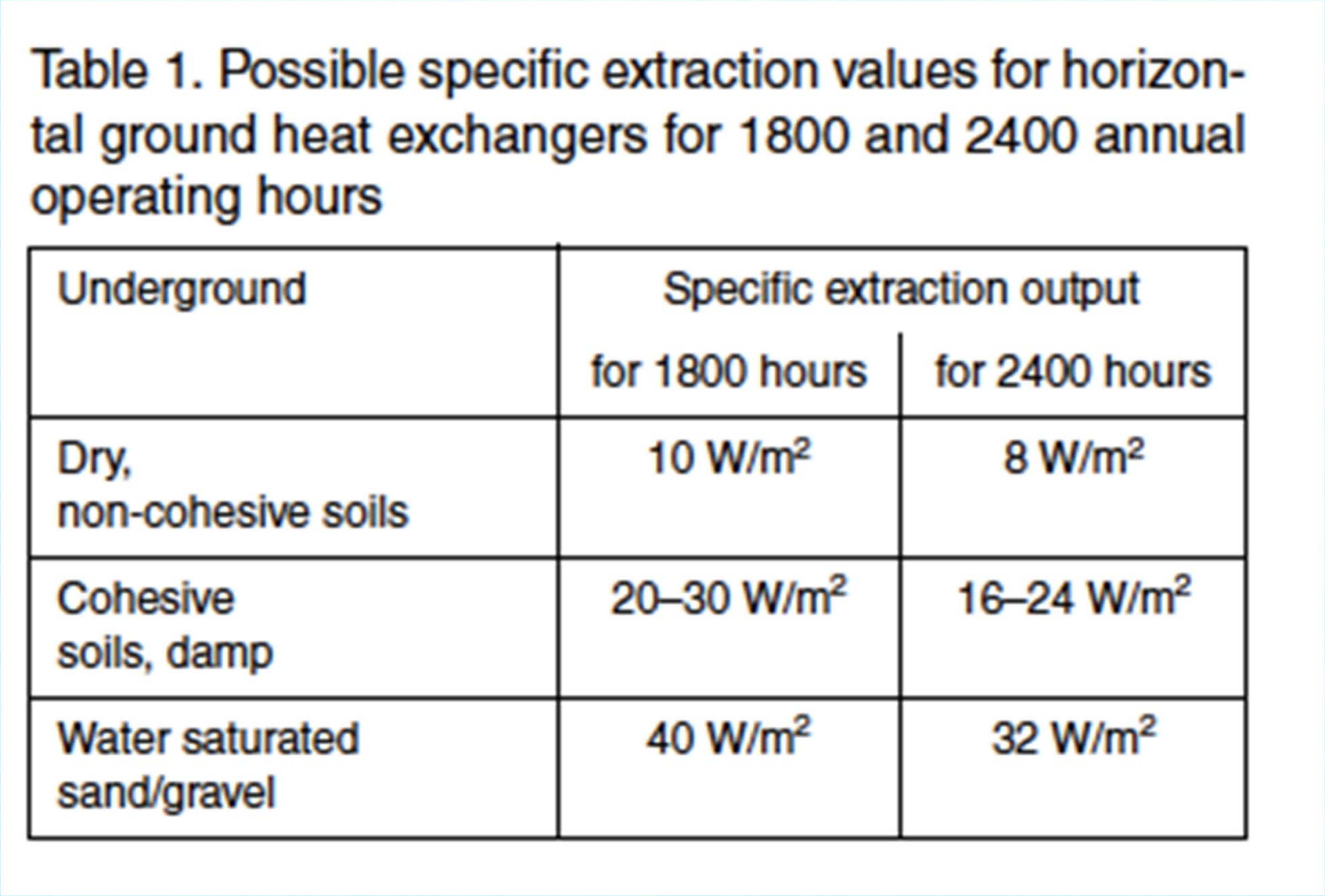


Table 1. Possible specific extraction values for horizontal ground heat exchangers for 1800 and 2400 annual operating hours

Underground	Specific extraction output	
	for 1800 hours	for 2400 hours
Dry, non-cohesive soils	10 W/m²	8 W/m²
Cohesive soils, damp	20–30 W/m²	16–24 W/m²
Water saturated sand/gravel	40 W/m²	32 W/m²

VDI 4640

Note the large differences
that arise from different k’s – alone.

No reference to min EWT – or period.

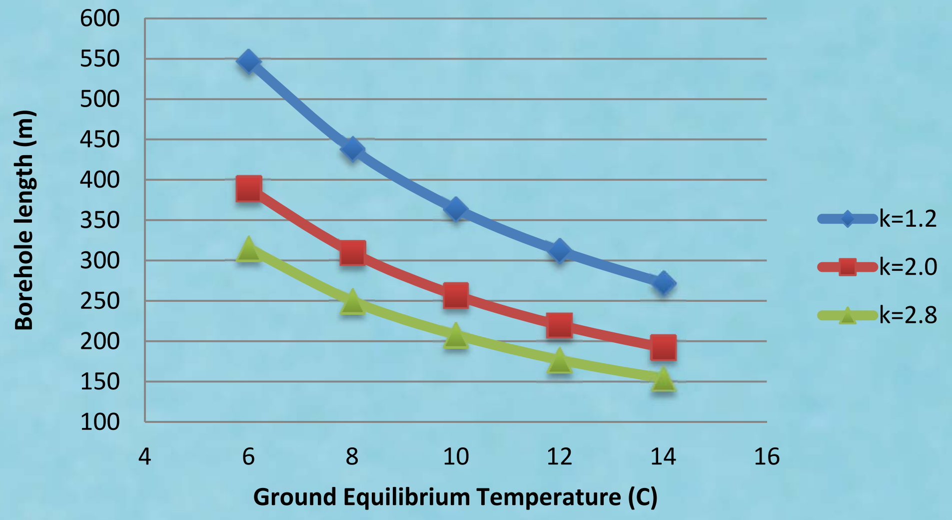
All for Double-Us (W’s?)

Note the references to
Central European
conditions.

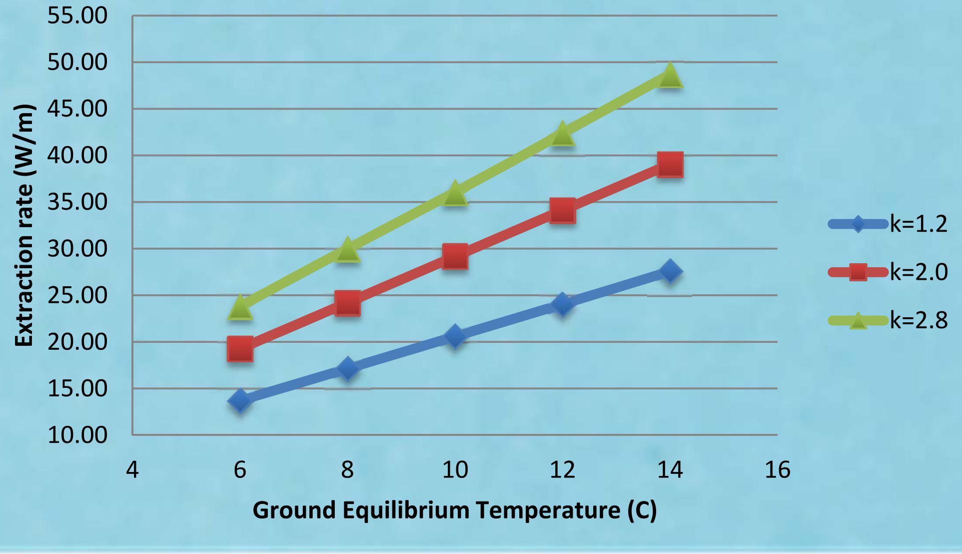
Also note North/South refs in VDI 4640

Preliminary scoping /exploratory exercises

to explore range of loop ground sizing.



10kW HP, Borehole, COP=3.5, 2400 hr
20 yrs EWT>0C



10kW HP, Borehole, 35C, 2400 hrs
20 years EWT>0C

10C	2.5W/m/K	1850 FLEQ	35C	120 mths	0C min EWT	168	Base Case	
				12 mths		150	-11%	poor practice
					-5C min EWT	108	-36%	poor practice
12C						141	-16%	genuine reduction
8C						207	23%	required increase
	1.8W/m/K					202	20%	required increase
		2400 FLEQ				177	5%	DHW ?
				240 mths		170	-1%	cf 120 months = 0k
			65C			127	-24%	interesting !

Sizing variation
(boreholes)

Horizontal: min EWT -1.1C 4.2kW

Location	Mean ground temp	Run hours	Ground type	Trench length	% change London
Cornwall	10.2	1840	heavy/sat	**31**	-31.1
Cornwall	10.2	1840	heavy/damp	**48**	-30.5
Cornwall	10.2	1840	heavy/dry	**61**	-29.7
Cornwall	10.2	1840	light/dry	**134**	-27.8
London	10.6	2094	heavy/sat	**45**	0
London	10.6	2094	heavy/damp	**70**	0
London	10.6	2094	heavy/dry	**86**	0
London	10.6	2094	light/dry	**186**	0
Aberdeen	8.4	2612	heavy/sat	**56**	24.8
Aberdeen	8.4	2612	heavy/damp	**88**	26.1
Aberdeen	8.4	2612	heavy/dry	**110**	26.9
Aberdeen	8.4	2612	light/dry	**239**	29

London – Heavy/damp ~4.2kW ~ 2100 run hours mean ground temp 10.2 C

Min EWT	Trench length
-2.2 C	58m
-1.1 C	70m
0.0 C	86m
1.1 C	111m

Possible matrix ?

Three locations
Three ground types
Two load patterns
(Load side temp COP/SPF ?)
for several HP sizes (<45kW?)

Suggested Matrix

3 Heat pump sizes – to cover MCS range 3.5 kW,10kW, 20kW and < 45kW

3 Ground types 1.2, 2.0, 2.8 W/mK

3 Ground temperatures 6C, 10C, 14C

2 Run hours 1800 and 2400.

For boreholes and/or trenches

Min EWT to be 0C after 20 years

Antifreeze ?

Grout ? Or borehole resistance?

SPF = 3.5

Boreholes

Concerns:
(re VDI 4640 primarily)

Equilibrium temperature

Min EWT

Analysis period.

Borehole extraction rates
all refer to double U.

Boreholes

Codes / methods available

VDI 4640 (manual)
GLHEPRO (IGSHPA)
EED
GLD
Manufacturers' Codes
CLGS (IGSHPA) – not used

1. BOREHOLE GROUND HEAT EXCHANGERS

NB – Read the small print…………………

Maximum power to be extracted per unit length of borehole heat exchanger (W/m) with 1800 FLEQ run hours

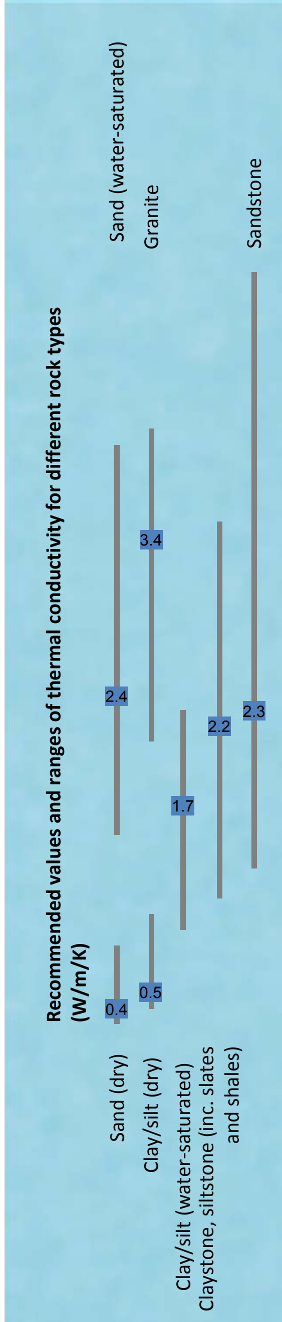
Conditions for use:

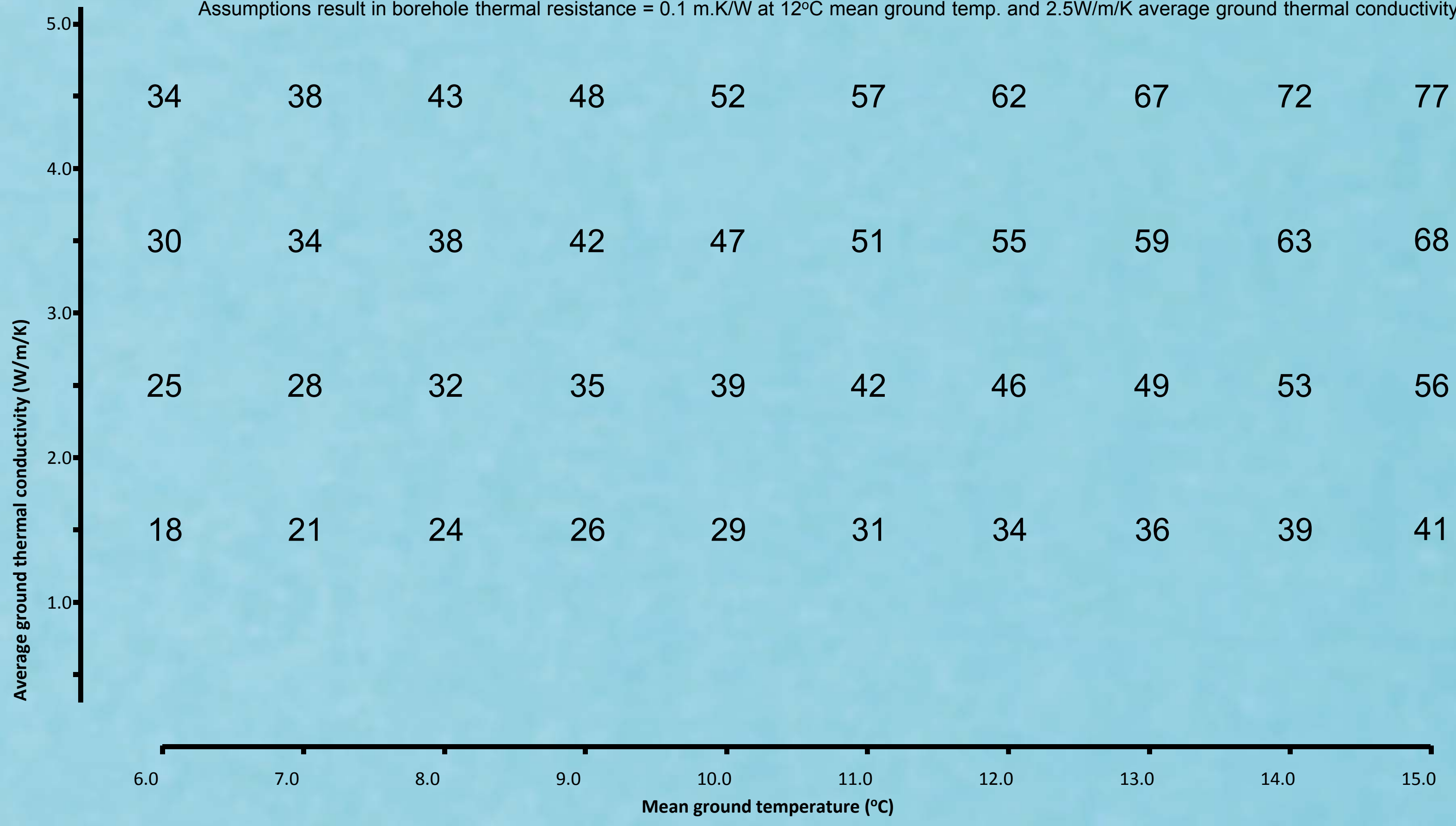
Heat extraction only (inc. hot water)

6m minimum borehole spacing. Only valid for boreholes arranged in a line; not applicable for a large number of systems in a small area

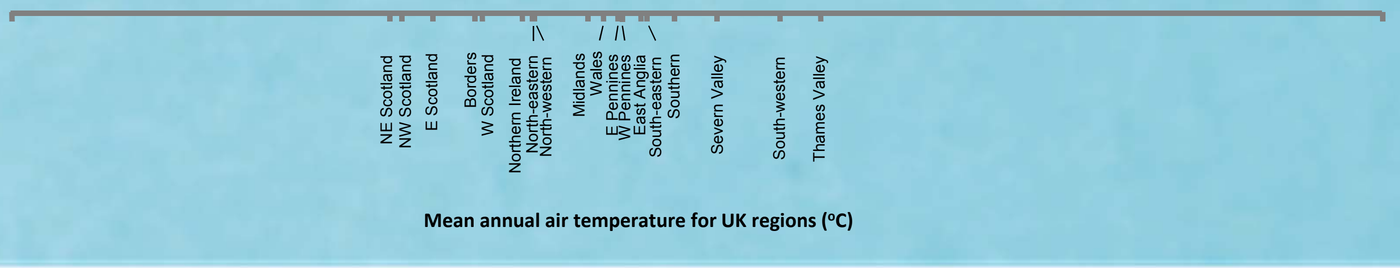
Table created assuming: 130mm borehole diameter; single U-tube; 32mm OD SDR-11, PE100 pipe with thermal conductivity = 0.420W/m/K; 52mm pipe centre-pipe centre shank spacing; 25% Mono Ethylene Gylcol thermal transfer fluid; Re > 2500 in the borehole active elements; thermally enhanced grout with thermal conductivity = 2.4W/m/K

Assumptions result in borehole thermal resistance = 0.1 m.K/W at 12^{o}C mean ground temp. and 2.5W/m/K average ground thermal conductivity





	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
	34	38	43	48	52	57	62	67	72	77
	30	34	38	42	47	51	55	59	63	68
	25	28	32	35	39	42	46	49	53	56
	18	21	24	26	29	31	34	36	39	41



Horizontal /”Trenched”

systems

(lots of interesting stuff
but
boreholes vs trenches
in the UK ?.....)

The Institution of Mechanical Engineers
The American Society of Mechanical Engineers

PROCEEDINGS OF THE

GENERAL DISCUSSION ON HEAT TRANSFER

11th—13th SEPTEMBER 1951

PUBLISHED BY THE INSTITUTION OF MECHANICAL ENGINEERS
STOREY'S GATE, ST. JAMES'S PARK, LONDON, S.W.1

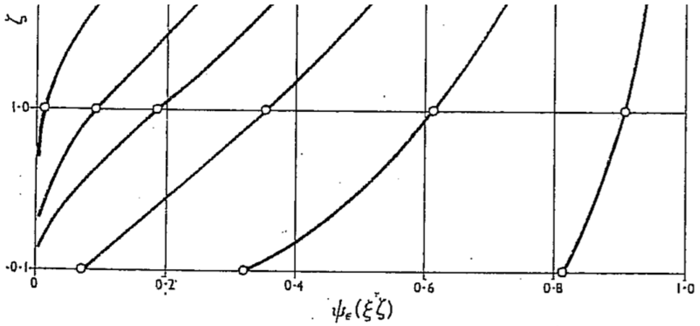


Fig. 22. Calculated Values of $\psi_\epsilon(\xi, \zeta)$ for $\epsilon = 10$

The results of the numerical calculation are compiled in Table 4, and for $\epsilon = 10$ are plotted in Fig. 22. Because of a lack of published experiments on the cooling of galleries by ventilation air, these results cannot be compared with experimental figures.

CONCLUSION

The conclusion can be drawn that, when cooling over a long distance, it must be expected that it will take a considerable time to approach a reasonable efficiency. For the example mentioned in the beginning of this section, it is found that at a distance of 1 kilometre from the cooling apparatus $(\xi{\sim}5)$ it will take about 20 days $(\zeta{\sim}2)$ to arrive at the fraction $\psi = 0{\cdot}5$ of the original temperature drop at the entrance.

Some Practical Applications of Heat Transfer between Buried Objects and the Soil

By Miss M. V. Griffith, B.Sc., and E. E. Hutchings, B.Sc. (Eng.)

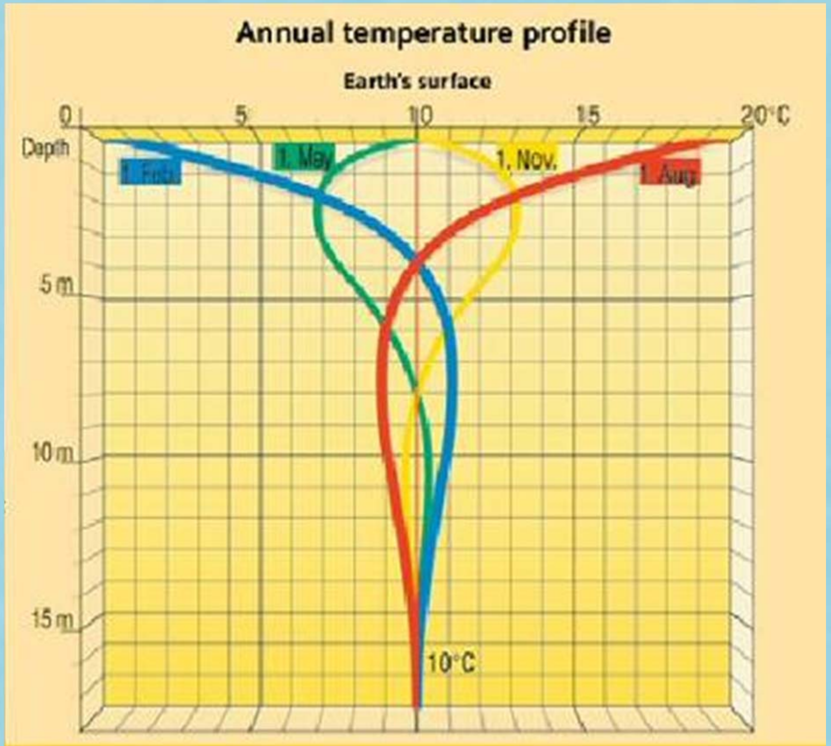
INTRODUCTION

Heat transfer enters to an important extent into problems concerning the thermal ratings of cables. Deterioration of cable insulants limits the temperature at which the conductors operate. The total thermal resistance from the conductor to the ultimate sink of heat is therefore a determining factor. With buried cables this comprises two parts: the internal thermal resistance of the cable from conductor to outer surface, and the external thermal resistance from the cable surface to the surface of the ground. This subject has been studied for at least thirty years; the principles are well established, and the theory is straightforward so long as the media concerned can be regarded as homogeneous. The latter assumption is often adequate in so far as the internal structure of modern cables is concerned, although difficulties have arisen from the complicated geometry of multi-core cables, especially those having non-circular conductors and discontinuities in the heat path. Satisfactory means of overcoming these difficulties have been devised, however, involving analogies between thermal and electrical flow and making use of electrolytic tanks, resistance-sheet models, and resistance networks, to obtain a solution to the Laplace equation in two-dimensional problems for specific cases.

In considering the external thermal resistance of a buried cable, the classical method assumes a semi-infinite medium with the ground surface isothermal, and the theory is developed from consideration of a cylindrical heat source and a corresponding image sink above the surface. Correct values must be assigned to the physical properties of the soil and to do this it has been necessary to study the medium in the conditions which actually

The MS. of this paper was received at the Institution of Mechanical Engineers on 2nd May 1951.

Ground temperature with depth



Annual temperature profile of the 'ground' heat source

High temperature stability makes the ground a good heat source

1m deep: 5-17ºC

>15m deep: 8-12ºC

is high. efficiently rejected underground.

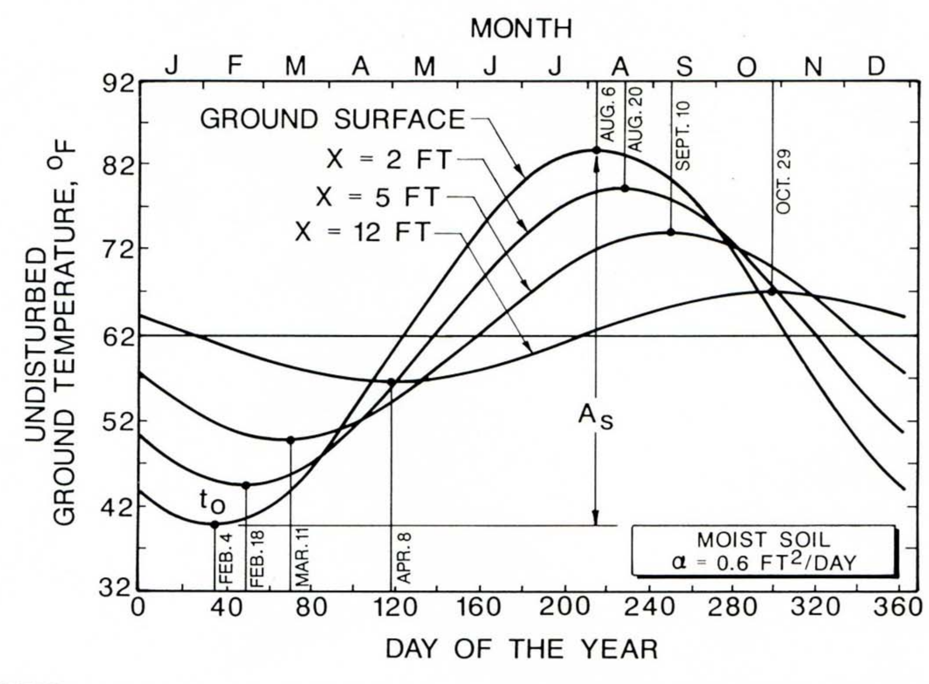
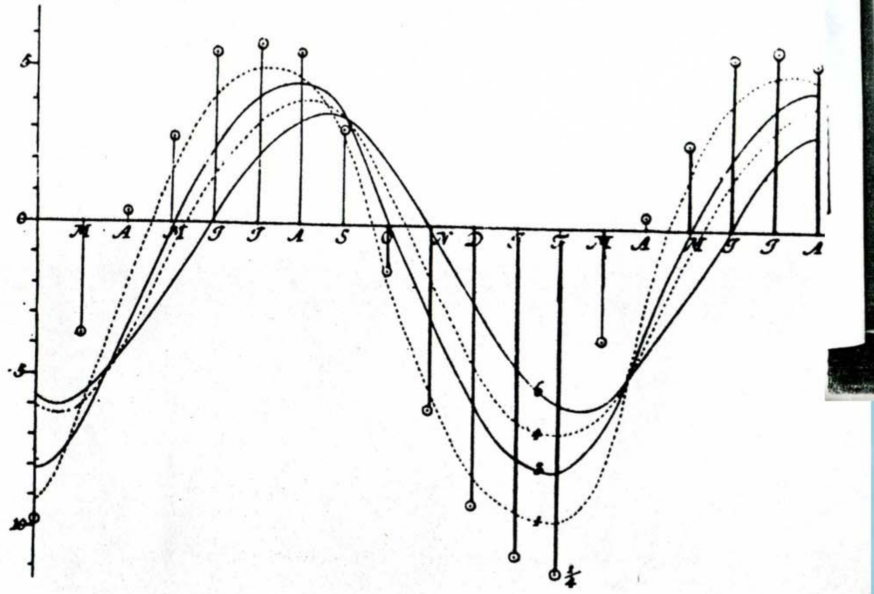
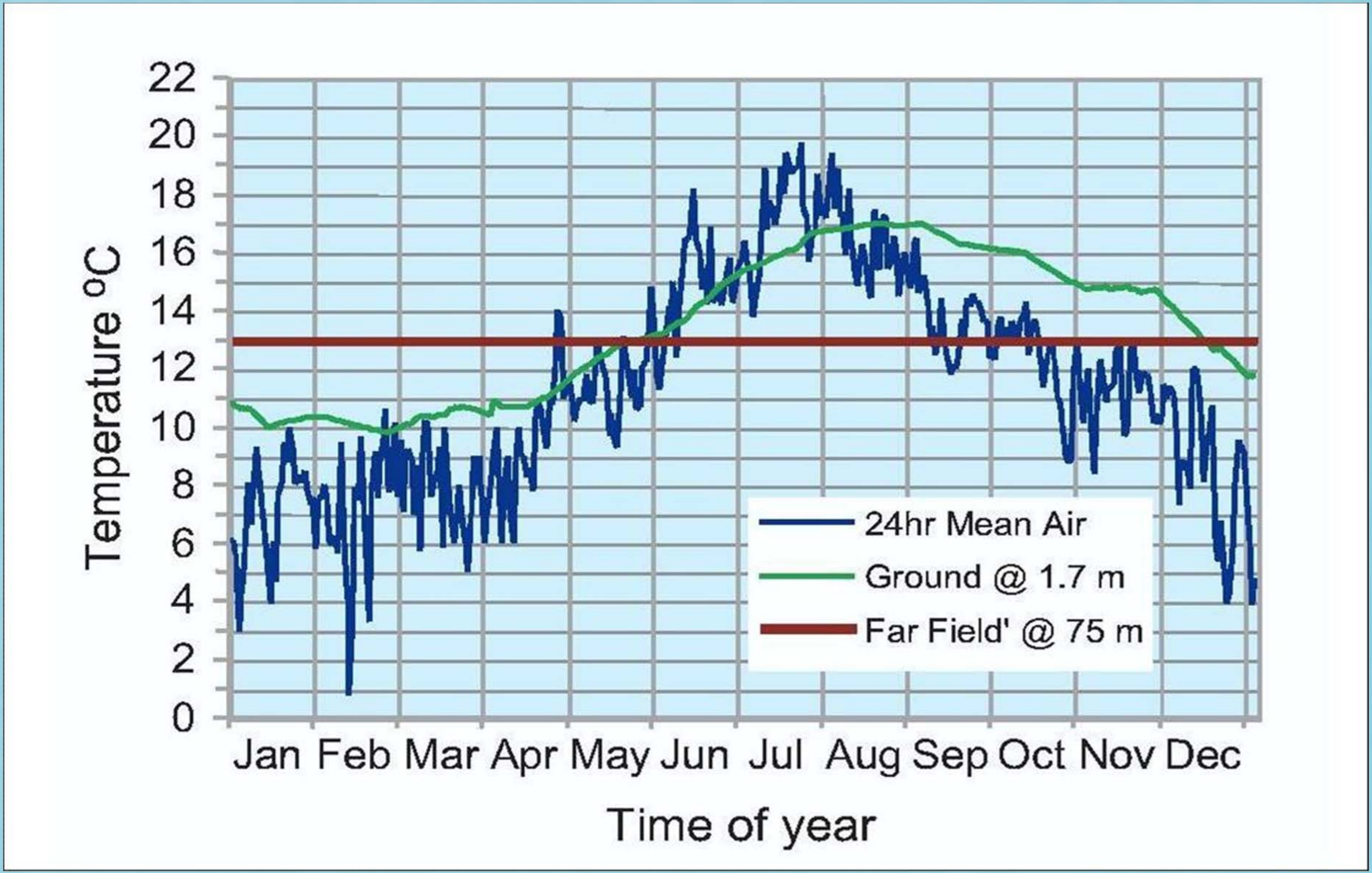


FIGURE 1.2: Annual Soil Temperature Variation, Stillwater, Oklahoma

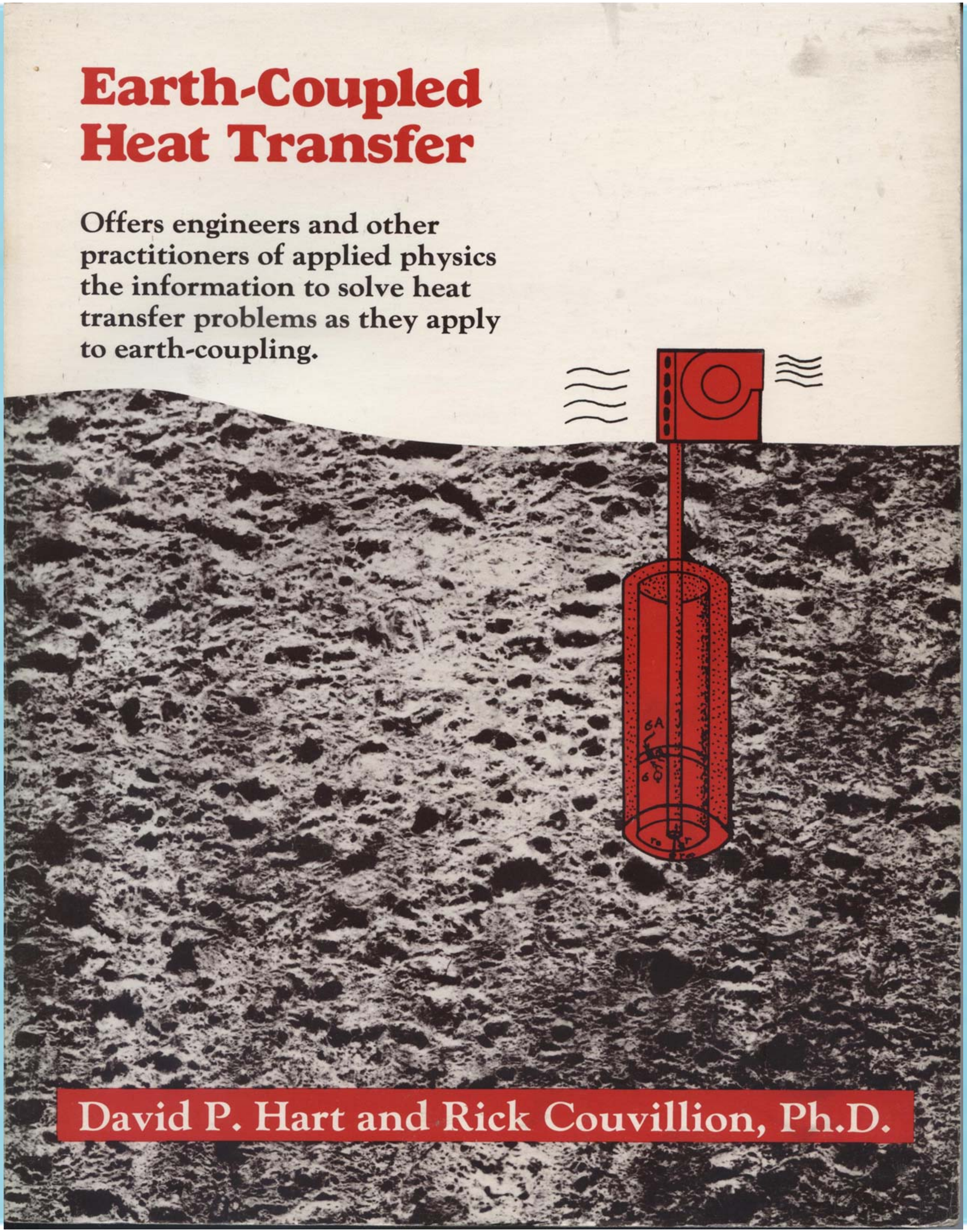


J. H. Lambert, *Pyrometrie* (Berlin, 1779).

from Tufte



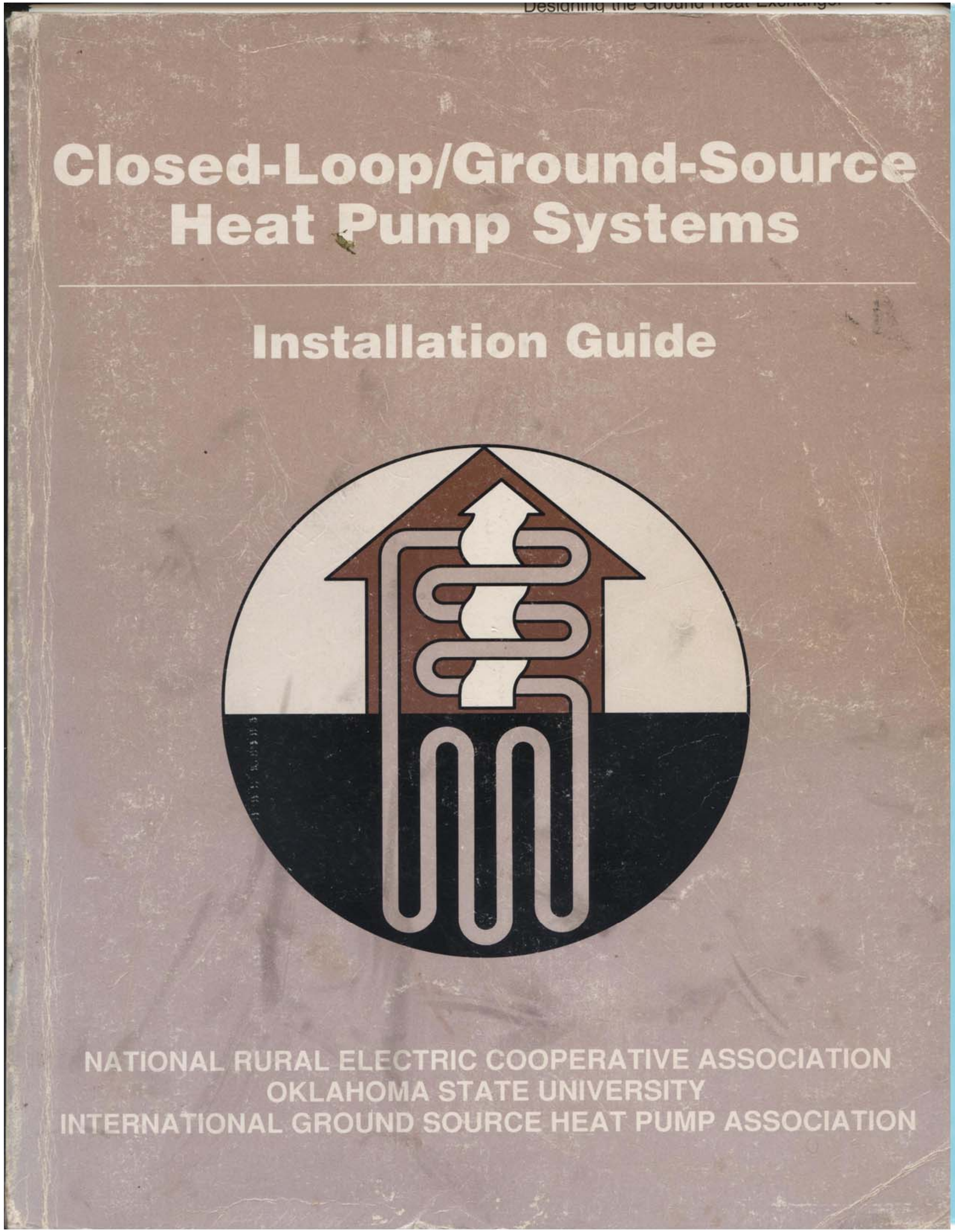
Falmouth measurements



Earth-Coupled Heat Transfer

Offers engineers and other practitioners of applied physics the information to solve heat transfer problems as they apply to earth-coupling.

David P. Hart and Rick Couvillion, Ph.D.



Closed-Loop/Ground-Source Heat Pump Systems

Installation Guide

NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION
OKLAHOMA STATE UNIVERSITY
INTERNATIONAL GROUND SOURCE HEAT PUMP ASSOCIATION

+work by Kavanaugh et al
from Alabama –
(beware the units !!)

Horizontal systems

Codes / methods available

VDI 4640 (manual)
CLGS (IGSHPA)
GLD
Manufacturers’ Codes

Straight pipe

The ground array was modelled using 10 parallel pipes of varying length.

The “effective area” used to calculate W/m^2 extracted was equal to pipe length x pipe separation x 10. i.e. a pipe influence of half the pipe separation was assumed for the two outer pipes.

25mm diameter pipe at a separation of 750mm and a depth of 750 mm was modelled for the look-up tables.

Depth decision

750 mm depth

These depths were finally used taking into consideration: water tables, changing saturation levels, frost heave, ploughing and digging , health and safety of trench depth and water utilities regulations.

Investigated:

Effect of thermal conductivity, depth and temperature swing on W/m^2 and W/m of a 10 pipe system, 762mm spacing 2400 run hrs with mean temp 10°C and 6°C

Effect of pipe separation on a 10 pipe system

The influence of spacing on a two pipe system

Effect of pipe diameter on a two pipe system

Effect of run hours, mean temperature with associated swing and thermal conductivity on a 10 pipe system and four pipe slinky equivalent for specific depth and spacing

Reduction in pipe needed by allowing entering water temperature to drop for an extreme case of 3600 run hours

Effect of thermal conductivity, depth, and temperature swing on W/m^2 extracted of a 10 pipe system, 762mm spacing 2400 run hrs with mean ground temp 10°Cand 6°C

A 10 pipe horizontal system was modelled at five different depths: 0.5 feet, 1.3 feet, 5.2 feet and 7.8 feet.

Five annual swing temperatures were used: 8.9°C, 11.2°, 13.4°, 15.6°, 22.2° at high, medium and low thermal conductivity.

These conditions were repeated with mean ground temperature of 10°C and 6°C.

All analysis with a building requiring 2400 run hours.

Using CLGS to produce straight pipe and slinky look-up tables

All systems

The heat pump modelled was a ClimateMaster CM019. Its output was 4.37 kW at an entering water temperature of 0° C which was maintained throughout the analysis. At this EWT the COP was 3.05 resulting in 2.93 kW extracted from the ground.

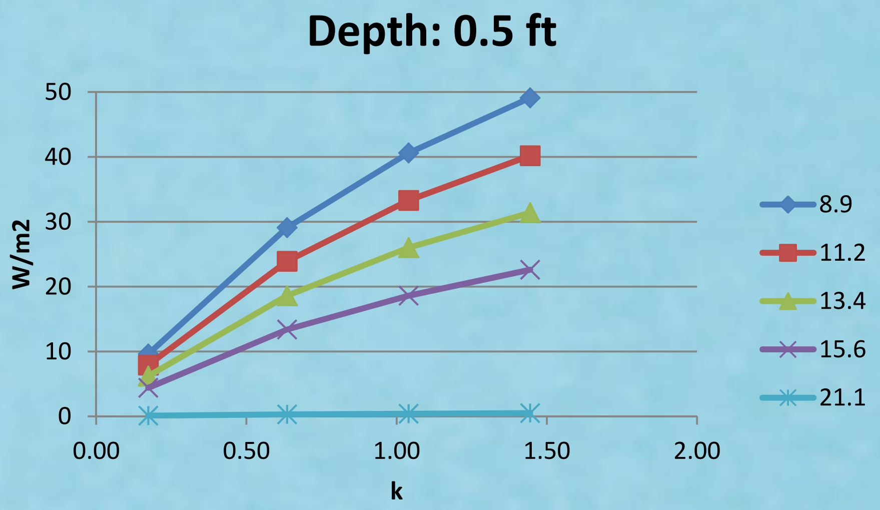
Polyethylene SDR-11 pipe with a thermal conductivity of 0.391 W/m.K was used throughout.

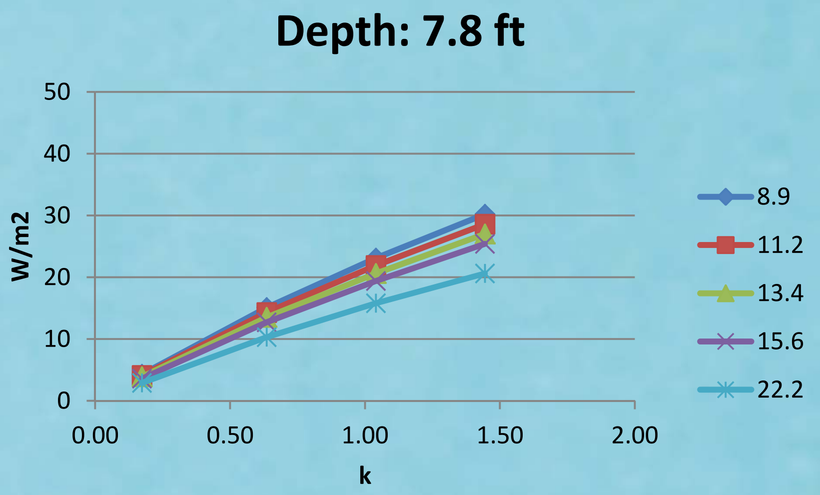
London air temperatures and different building loads were used to vary the heat pump run hours from 1200 to 3600. Outside design temperature, indoor design temperature and winter balance temperature of -6.7°C, 21.1°C, and 20°C were used respectively.

The following ground conductivities and thermal diffusivities were used:

	Conductivity W/m.K	Diffusivity cm2/s
High	2.7	0.0090
Medium	1.4	0.0064
Low	0.4	0.0039

Effect of depth and annual swing on W/m² extracted (10°C mean air temp)

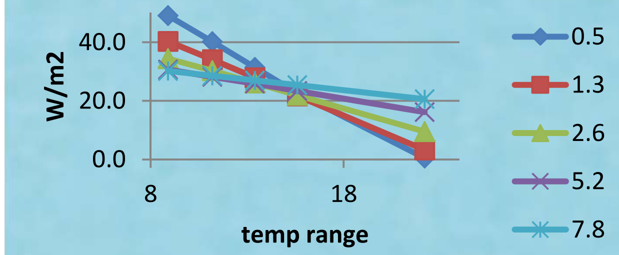

Depth: 0.5 ft

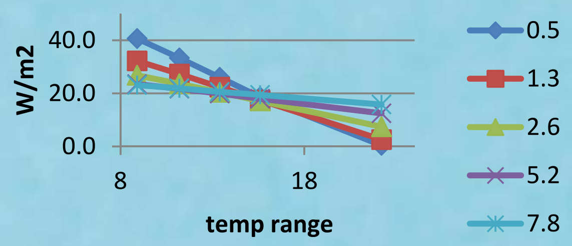

Depth: 7.8 ft

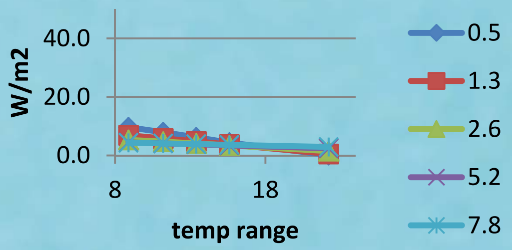
Increasing depth resulted in higher system performance when thermal conductivity was low and the annual swing was high. The shallower systems had improved system performance when the annual swing temperature was low.

Effect of depth and annual swing on W/m² extracted

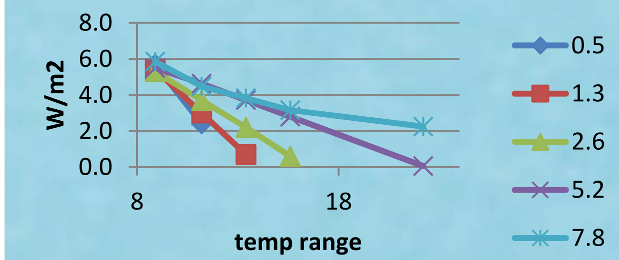
Crossover point, 10°C mean air temp

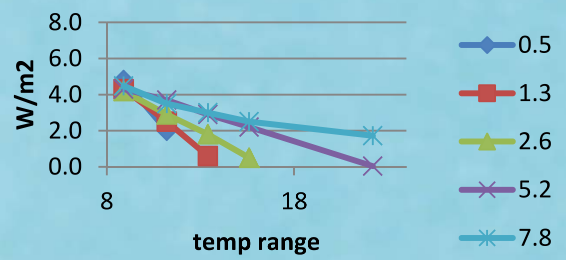

k = 2.5 W/m

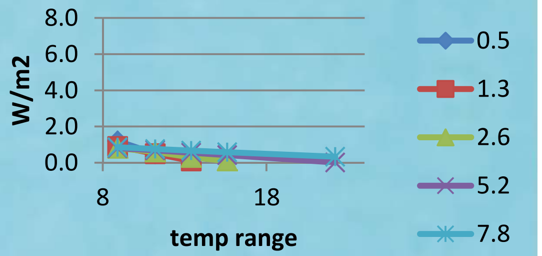

k = 1.8 W/m


k = 0.3 W/m

Crossover point, 6°C mean air temp

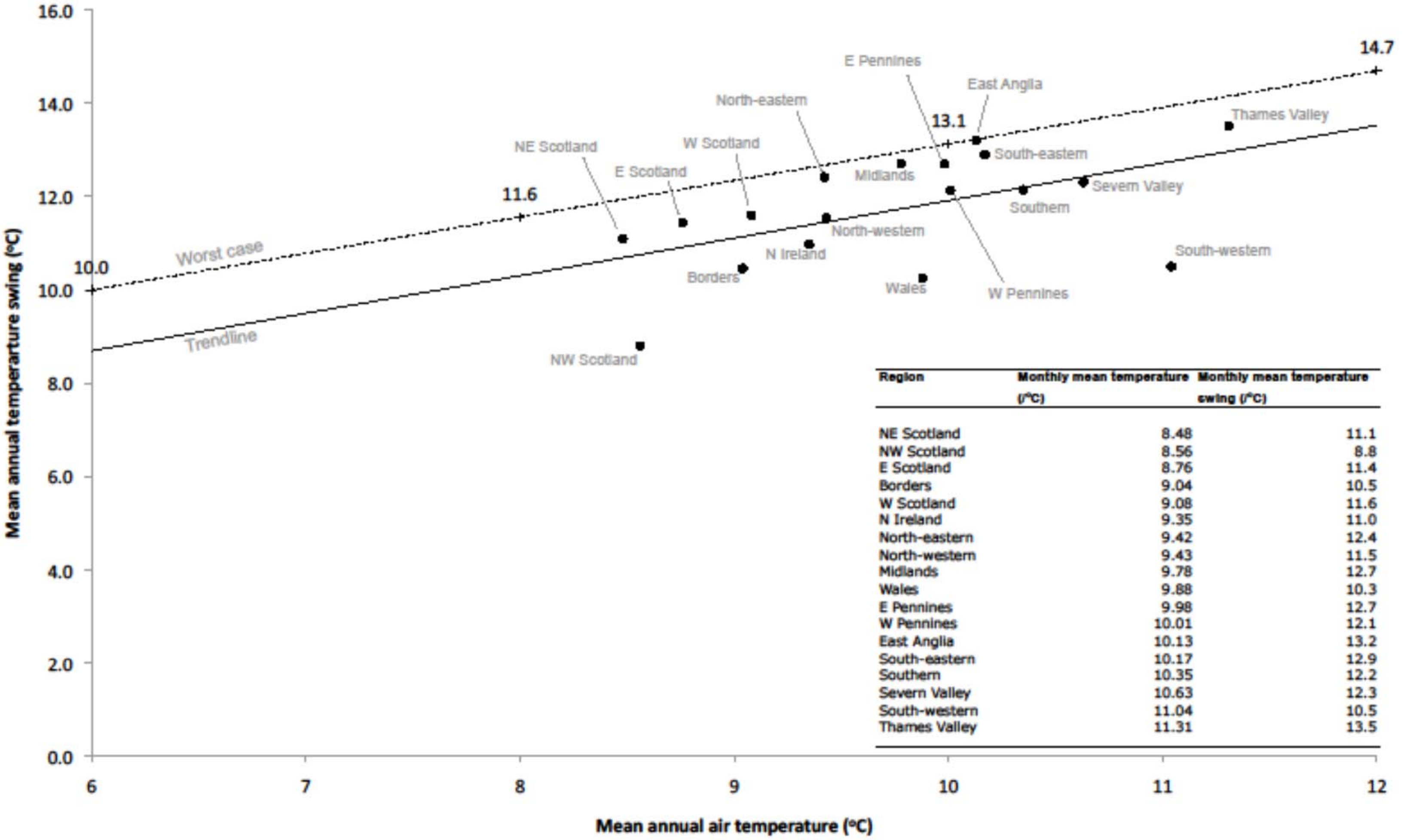

k = 2.5 W/m


k = 1.8 W/m


k = 0.3 W/m

A “crossover point” of about 15°C annual swing occurred when the mean ground temperature was 10°C. At swing temps below this point, increased system performance was seen at all depths and thermal conductivies. This crossover point lowered to about 10°C annual swing when the mean ground temperature was 6°C.

Mean air temp v mean temp swing: correlation?



Region	Monthly mean temperature (/°C)	Monthly mean temperature swing (/°C)
NE Scotland	8.48	11.1
NW Scotland	8.56	8.8
E Scotland	8.76	11.4
Borders	9.04	10.5
W Scotland	9.08	11.6
N Ireland	9.35	11.0
North-eastern	9.42	12.4
North-western	9.43	11.5
Midlands	9.78	12.7
Wales	9.88	10.3
E Pennines	9.98	12.7
W Pennines	10.01	12.1
East Anglia	10.13	13.2
South-eastern	10.17	12.9
Southern	10.35	12.2
Severn Valley	10.63	12.3
South-western	11.04	10.5
Thames Valley	11.31	13.5

After investigating mean and swing temperatures, the following values were used:

Mean ground temperature °C	Annual swing °C
6	9.0
8	10.4
10	11.8
12	13.2

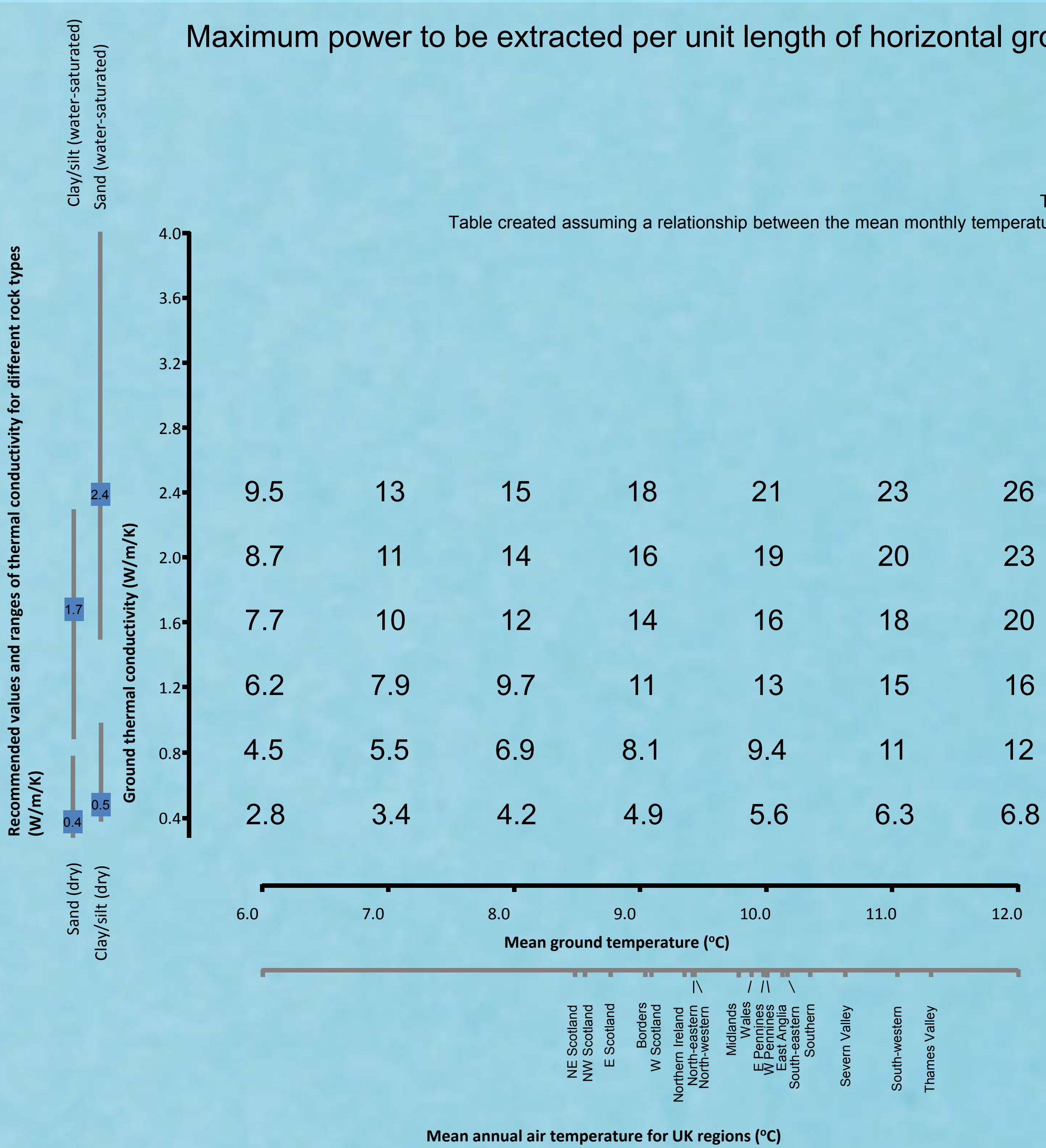
2. HORIZONTAL GROUND HEAT EXCHANGERS

NB - read the small print

Maximum power to be extracted per unit length of horizontal ground heat exchanger (W/m) with 1800 FLEQ run hours

Conditions for use:

Heat extraction only (inc. hot water)
0.75m minimum pipe spacing (d > 0.75m)
Pipe depth between 0.8m and 1.2m
Table created assuming 25mm OD SDR 11 pipe
Table created assuming a relationship between the mean monthly temperature swing and annual mean ground temperature



Ground thermal conductivity (W/m/K)	6.0	7.0	8.0	9.0	10.0	11.0	12.0
2.4	9.5	13	15	18	21	23	26
2.0	8.7	11	14	16	19	20	23
1.6	7.7	10	12	14	16	18	20
1.2	6.2	7.9	9.7	11	13	15	16
0.8	4.5	5.5	6.9	8.1	9.4	11	12
0.4	2.8	3.4	4.2	4.9	5.6	6.3	6.8

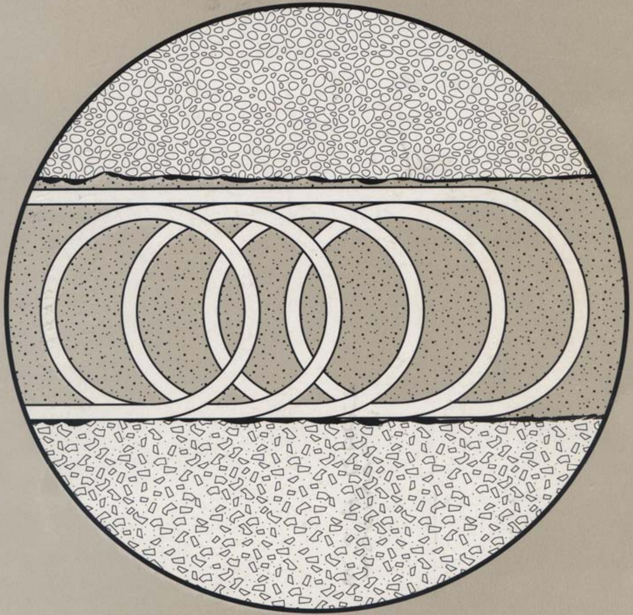
Horizontal /”Trenched”

systems

“Slinkies”

Closed-Loop Geothermal Systems

Slinky® Installation Guide



NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION
OKLAHOMA STATE UNIVERSITY
INTERNATIONAL GROUND SOURCE HEAT PUMP ASSOCIATION
ELECTRIC POWER RESEARCH INSTITUTE

“Slinkies”

Modeled using CLGS
as 4 pipes in a plane

Comparison between four pipe per trench horizontal and vertical arrangements

Effect of run hours, mean temperature with associated swing and thermal conductivity on a four pipe slinky equivalent for specific depth and spacing (resulting in look-up tables)

Reduction in pipe needed by allowing entering water temperature to drop for an extreme case of 3600 run hours

Comparison between CLGS slinky method and multiple pipe slinky representation

Effect of slinky pitch on W/m trench

Effect of area lost due to slinky overlap on the optimising of slinky pitch with changing ground conductivity

Slinkys

4 pipes per trench at a separation of 273mm (=820mm trench width and therefore slinky diameter) were used to represent the horizontal slinky system.

4 trenches of varying length with centres 3m apart were used to represent the ground array.

32mm diameter pipe at a depth of 1200 mm was modelled for the look-up tables.

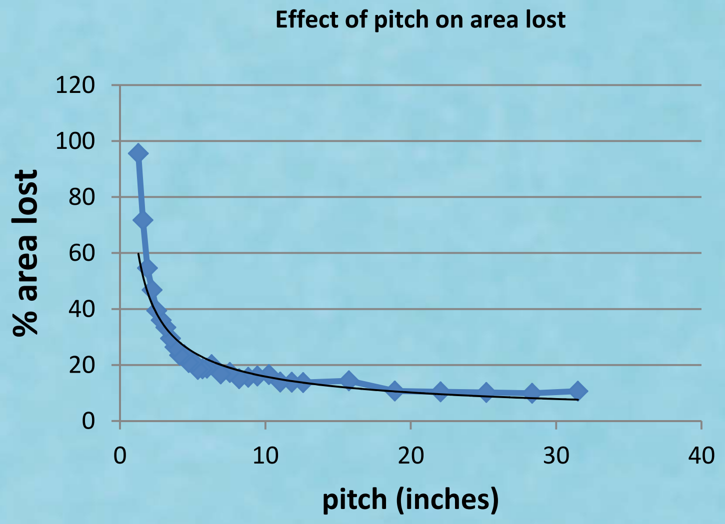
W/m^2 extracted was not estimated in the slinky representation as “effective area” was unknown.

Depth decision

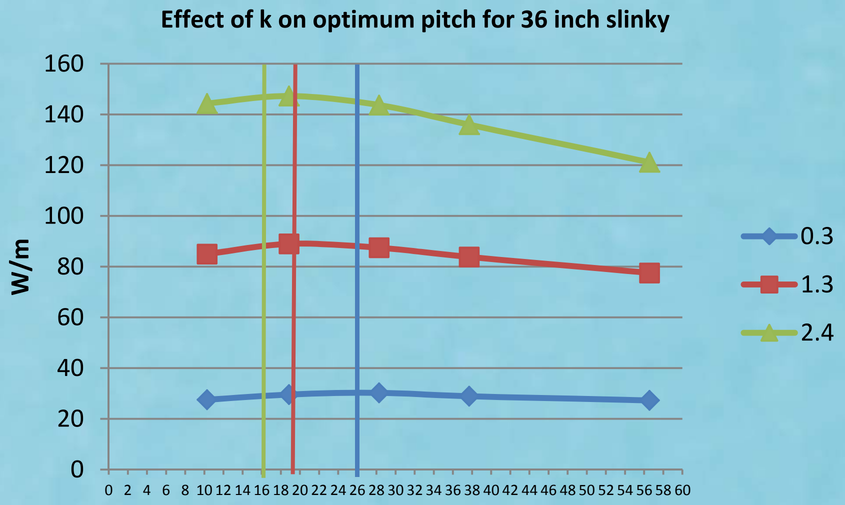
1200mm depth for horizontal slinky (1200mm mid depth for vertical slinky leaving top of loop 750mm deep if 900mm diameter slinky).

These depths were finally used taking into consideration: water tables, changing saturation levels, frost heave, ploughing and digging , health and safety of trench depth and water utilities regulations.

Effect of area lost due to slinky overlap on the optimising of slinky pitch with changing ground conductivity



Effect of pitch on area lost



Effect of k on optimum pitch for 36 inch slinky

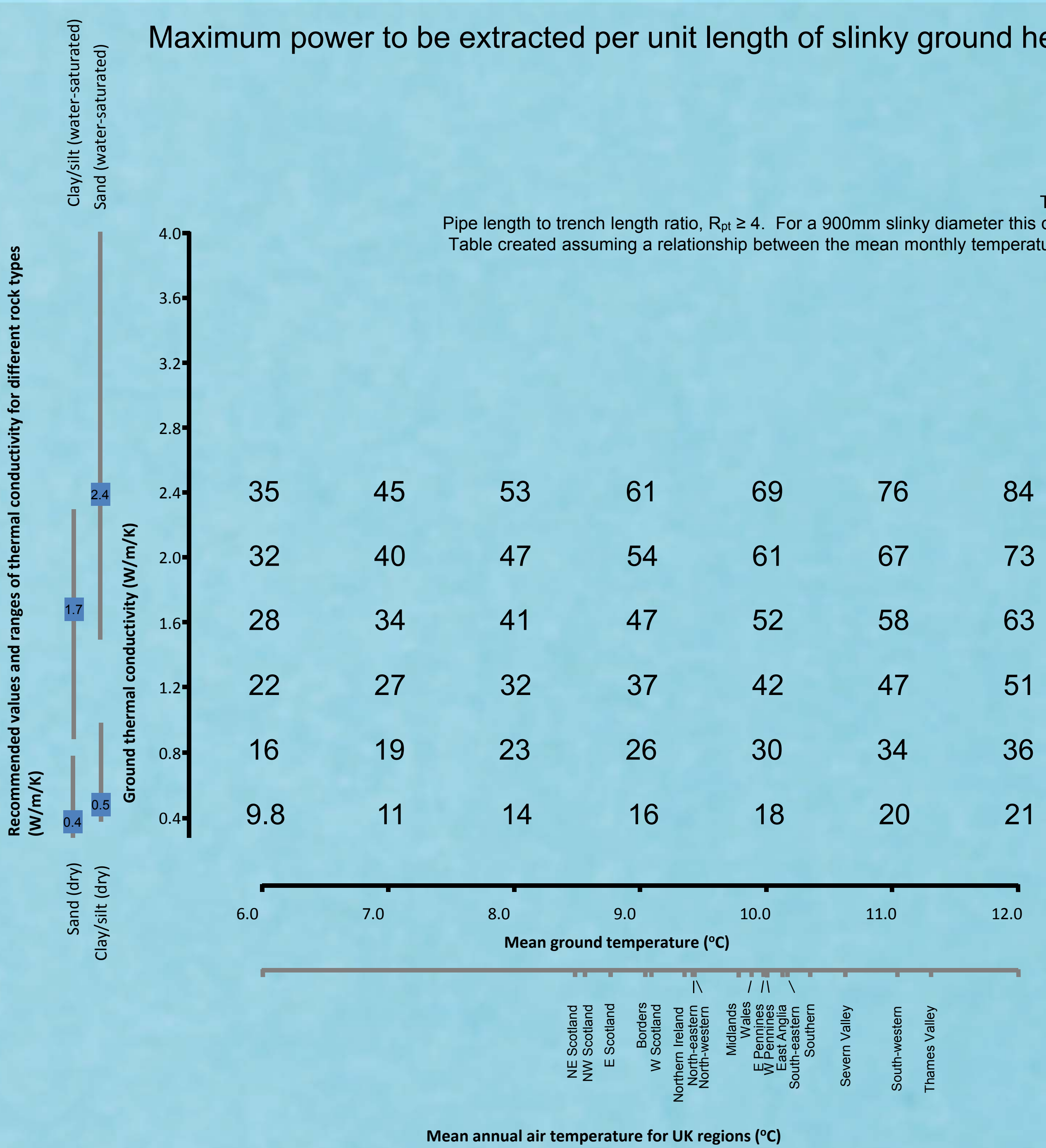
3. SLINKY GROUND HEAT EXCHANGERS

NB - read the small print

Maximum power to be extracted per unit length of slinky ground heat exchanger trench (W/m) with 1800 FLEQ run hours

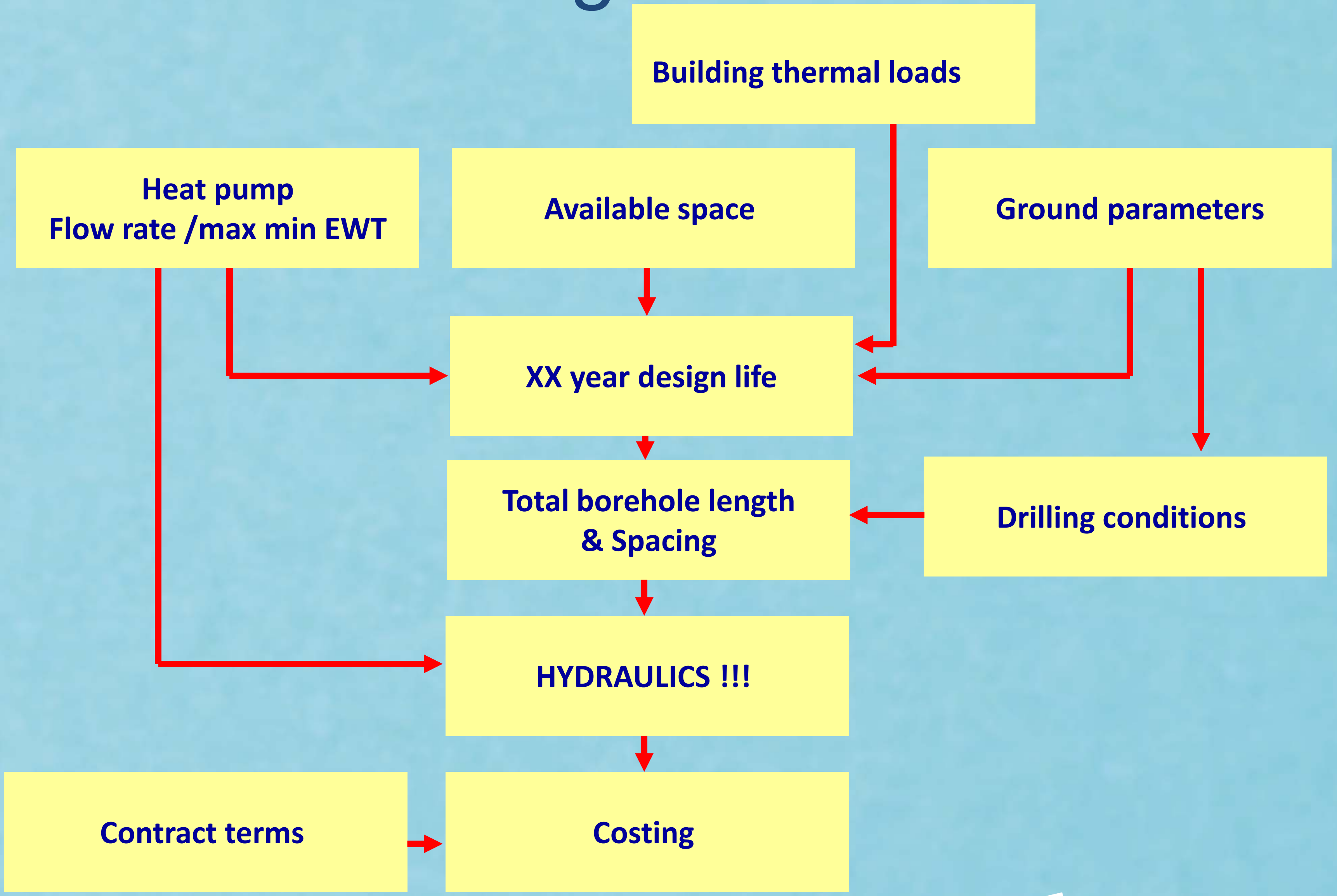
Conditions for use:

Heat extraction only (inc. hot water)
3m minimum trench spacing (d ≥ 3m)
Mean slinky depth between 0.8m and 1.2m
Table created assuming 32mm OD SDR 11 pipe
Pipe length to trench length ratio, $R_{pt} \geq 4$. For a 900mm slinky diameter this corresponds to a maximum 1250mm slinky pitch
Table created assuming a relationship between the mean monthly temperature swing and annual mean ground temperature



Ground thermal conductivity (W/m/K)	6.0	7.0	8.0	9.0	10.0	11.0	12.0
2.4	35	45	53	61	69	76	84
2.0	32	40	47	54	61	67	73
1.6	28	34	41	47	52	58	63
1.2	22	27	32	37	42	47	51
0.8	16	19	23	26	30	34	36
0.4	9.8	11	14	16	18	20	21

Design Process



Building thermal loads

Heat pump
Flow rate /max min EWT

Available space

Ground parameters

XX year design life

Total borehole length
& Spacing

Drilling conditions

HYDRAULICS !!!

Contract terms

Costing

GeoEnergy

Hydraulics ?!

TABLE OF CONTENTS

1. BOREHOLE GROUND HEAT EXCHANGERS 4
    - 1200 FLEQ run hours 5
    - 1800 FLEQ run hours 6
    - 2400 FLEQ run hours 7
    - 3000 FLEQ run hours 8
    - 3600 FLEQ run hours 9
2. HORIZONTAL GROUND HEAT EXCHANGERS 10
    - 1200 FLEQ run hours 11
    - 1800 FLEQ run hours 12
    - 2400 FLEQ run hours 13
    - 3000 FLEQ run hours 14
    - 3600 FLEQ run hours 15
3. SLINKY GROUND HEAT EXCHANGERS 16
    - 1200 FLEQ run hours 17
    - 1800 FLEQ run hours 18
    - 2400 FLEQ run hours 19
    - 3000 FLEQ run hours 20
    - 3600 FLEQ run hours 21
4. AMENDMENTS ISSUED SINCE PUBLICATION 22

Remember…

Designed as a backstop conservative design

More “knowledge” = “better” design

Role for the GSHPA ?

Adopt these tables

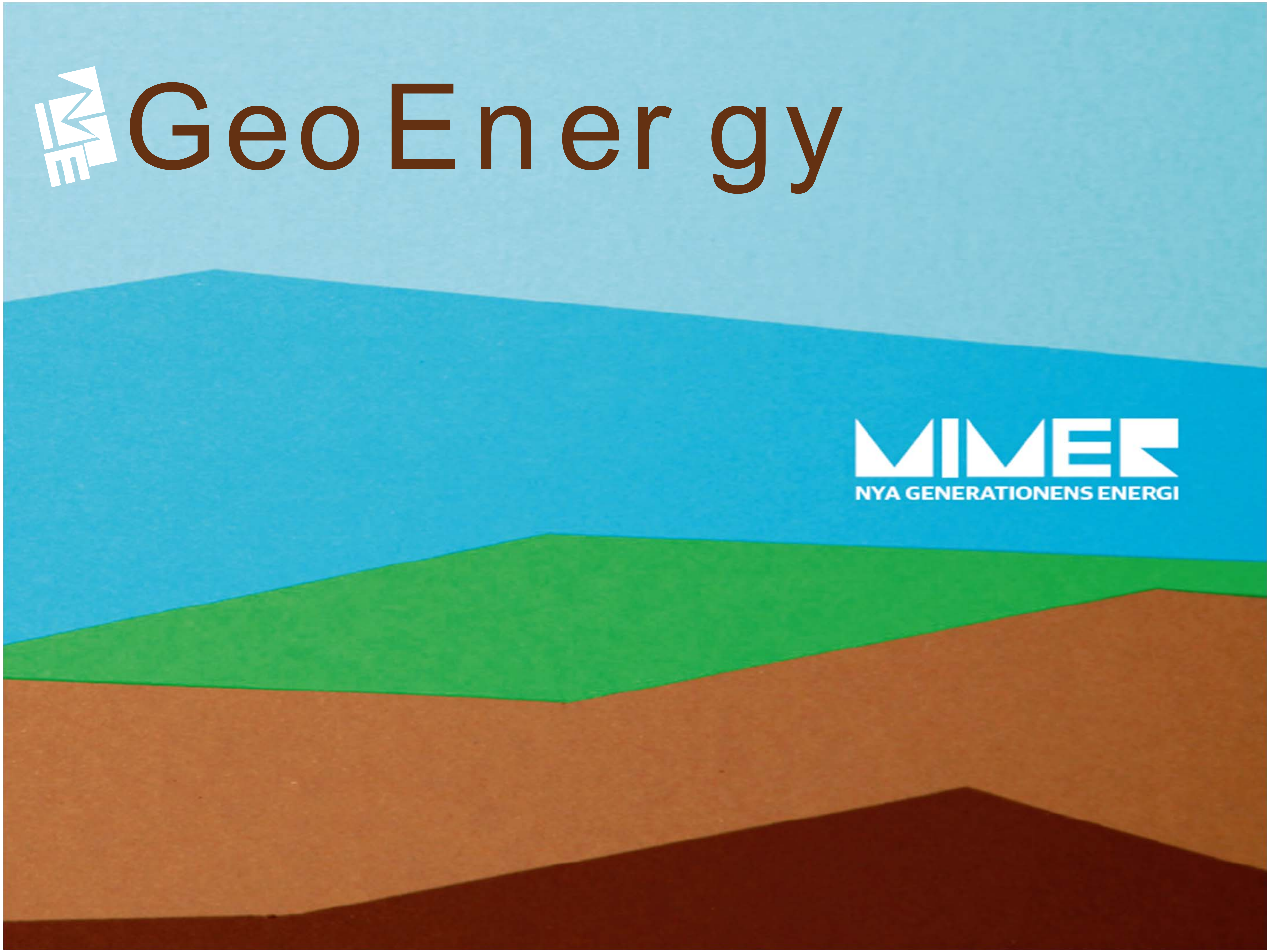
Document them and the process

(Peer?) Review, Revise and Update……

4. AMENDMENTS ISSUED SINCE PUBLICATION

Issue Number:	Amendment Details:	Date:
1.0	First issue	24/08/2011

GeoEnergy



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