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Life Cycle Energy Assessment & Further Options

Work Packages 1.7 and 1.8

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1 INTRODUCTION

This report contains an assessment of the life cycle energy requirement for typical re-circulating pipework systems in buildings. The findings of the research are used to put forward new proposals for pipe sizing criteria and to identify other issues that will help to reduce pump energy requirements in buildings.

The report is the output of Work Packages 1.7 and 1.8 of the BRE Trust/BSRIA funded project "Design Of Energy Efficient Pumping Systems" (DEEPS). The DEEPS research programme aims to identify the issues affecting pump energy, and to produce an authoritative guide on how to minimise pump energy consumption in the building services sector.

The objective of Work Package 1.7 is to calculate the optimum pipe sizing criteria necessary to minimise the life cycle energy requirement for re-circulating pipework systems. In simple terms, the research will determine how pipes and associated fittings should be sized in order to minimise the life cycle energy footprint of the system, i.e. the embodied energy required to fabricate the pipes in the first place, plus the pump energy that will be consumed over the life of the system.

1.1 BACKGROUND

Work Package 1.4 (Industry Stakeholder Liaison) identified the need to establish clear criteria to govern the sizing of pipes in heating and cooling systems. There is a direct link between pipe size, pressure loss, pump size and the resulting pump energy consumed.

Feedback from the Stakeholder Liaison indicated that for most design engineers, the aim during pipe sizing is usually to select a pipe that can accommodate the required flow of water whilst incurring the minimum installed cost of the combined pipework system and pump. (For most design engineers, pump energy is not the main issue.) If pipes are sized with relatively high pressure losses, this will result in smaller, cheaper pipework but, due to the increased resistance of the pipes, a larger more powerful pump that uses more energy over the life of the system.

There is a commonly quoted rule of thumb that pipes should be sized with a maximum pressure loss in the range 200-300 Pa/m for all re-circulating pipework systems. This advice appears in design guides relevant to the UK, USA and other parts of Europe. The origins of this guidance are not acknowledged in any of the sources.

In order to evaluate the most energy efficient pipe sizing method, the embodied energy of the installed pipework must be taken into account, i.e. the energy required to produce the pipes in the first place. For example, it would be possible to achieve very low pump energy consumptions by increasing pipe sizes so that pressure losses were minimal. However, any energy saving achieved would to some extent be negated by the increase in the embodied energy of the installed pipes.

It can be seen that a balance has to be struck between the life cycle pump energy requirements of a system and the embodied energy requirement of its pipework. This report addresses this issue and aims to provide guidance on pipe sizing that takes into account lifecycle energy consumption.

2 METHOD

2.1 EXAMPLE SYSTEM

An example pipework system layout has been developed that is considered to be representative of commercial sized heating and chilled water systems. A diagram of the example system is included in Appendix A to this report.

The example system comprises a standard flow and return pipework system with nominal pipe sizes ranging from 15mm to 250mm in diameter. The distance between branches is 3 m since this corresponds to the distance between the different floor levels in a building; it also corresponds with the typical distance between cellular office zones in open plan office areas.

Each of the terminal units fed from the example system has a design flow rate of 0.2 kg/s which is the flow required to deliver approximately 5.0 kW of cooling to each terminal unit at a design temperature differential of 6°C, or 8.4 kW of heating at a design temperature differential of 10°C.

The example system serves 10 levels each of which have 50 terminal units, all connected off a single straight pipe branch.

2.2 PUMP LIFE CYCLE ENERGY CONSUMPTION

For the purposes of determining typical pump life cycle energy consumptions for the example system, a number of assumptions have been made as outlined in the following sections 2.2.1 to 2.2.7.

2.2.1 Pipe sizes and pressure losses

All pipes in the example pipework system have been selected from the range of heavy grade steel pipes from BS 1387:1985 (EN 10255) *Specification for screwed and socketed steel tubes*. The density and viscosity of water at 10°C have been used as the basis for generating pipe sizing tables using the CIBSE guide C4 pipe sizing spreadsheet. Pipes have been sized using this spreadsheet, based on limiting pressure drop per metre values ranging from 50 Pa/m to 700 Pa/m at 50 Pa/m intervals. Pipe sizes have been selected such that the pressure losses in straight pipes do not exceed the stated limiting pressure drop per metre. Pipes have also been sized such that the flow velocities in the pipes do not exceed CIBSE recommended limits of 1.5 m/s for pipes less than 50 mm diameter, or 3.0 m/s for pipes larger than 50 mm diameter.

Pipe pressure losses have been calculated by multiplying the pipe straight lengths by their estimated pressure losses per metre. Pressure losses through fittings such as tees, elbows, reductions and enlargements have been estimated using the published pressure loss coefficients (otherwise known as “zeta values”) from CIBSE Guide C4 *Flow of fluids in pipes and ducts*.

Terminal branch pressure losses have been estimated on the assumption that they could contain up to 8 elbows (4 in the flow pipe and 4 in the return), and the pressure losses through the terminal unit and associated valves will be 10 kPa.

2.2.2 Calculation of pump energy

For each limiting Pa/m value, a different range of pipe sizes have been selected for the example system. For each alternative set of pipe sizes, an estimate has been made of the pump energy required to circulate the water. This estimate uses the following equation to determine pump power.

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$$P = \Delta P.Q / \eta$$

Where,

P = pump power (W)
ΔP = pump pressure differential (Pa)
Q = flow rate (m^3/s)
η = overall pump efficiency

2.2.3 Pump efficiency

The efficiency of a pump will depend on the pump selected and the relative position of the operating point relative to the pump efficiency curve. For simplicity, it has been assumed that a pump efficiency of 60% is achievable in all cases.

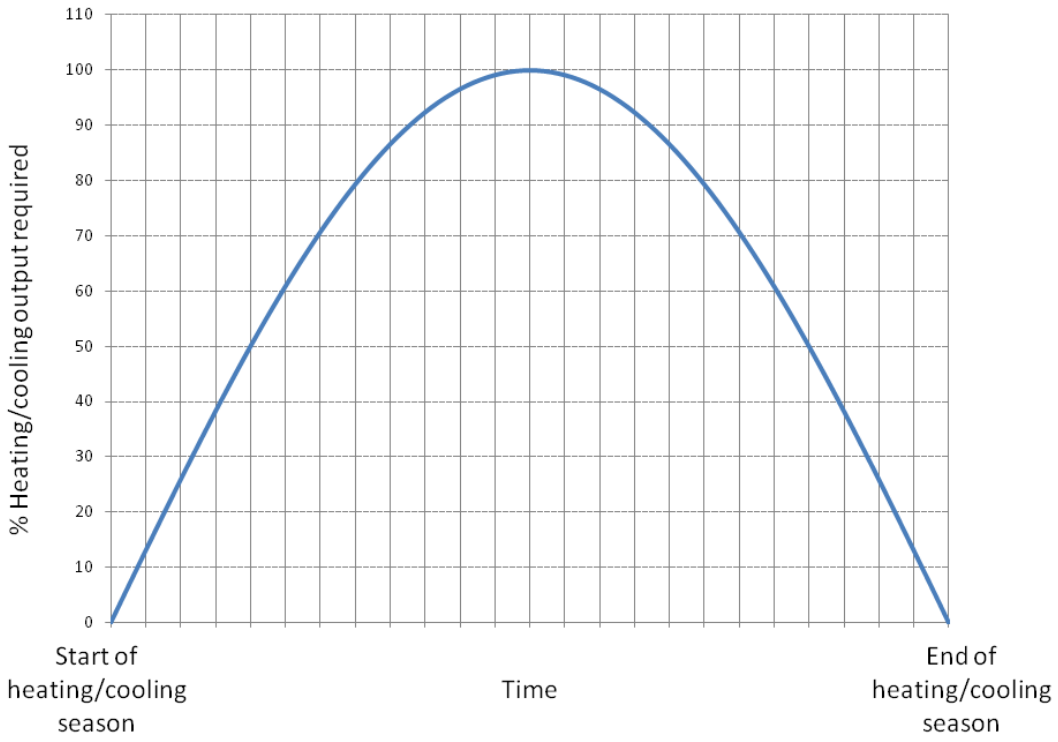
2.2.4 Variations in pump flow rate

For constant flow systems, the power consumed by the pump will be constant all the time the pump is operating. Although less common in the UK, the survey of design engineers conducted as part of work package Work Package 1.4 (Industry Stakeholder Liaison) revealed that some design engineers still design constant flow systems. Hence, constant flow systems are included as part of this comparison.

However, most re-circulating pipework systems are designed as variable flow systems in which the pump has the opportunity to reduce its speed under part load conditions, thereby reducing its energy consumption. In order to estimate the average flow rate through a system that varies its flow in response to demand some assumptions have been made about the likely operating pattern of a typical heating or cooling system.

First of all, it has been assumed that the total heating or cooling requirement from the system will vary across the heating or cooling season, approximately following the pattern of a sine curve as shown in Figure 1. The requirement for heating or cooling will gradually increase until it reaches the coldest part of the winter, or hottest part of the summer. It will then gradually reduce again as the season changes.

Figure 1 Typical pattern in heating/cooling demand across a heating or cooling season



It should be noted that this relationship is not precise and it assumes that the heating and cooling loads in the building follow a close correlation with external temperature conditions. This may not always be the case as other factors may influence the demand for heating or cooling such as:

- Heating system pre-heat times may cause longer periods at 100% capacity than are reflected by the curve.
- System and terminal unit over-sizing may cause the system not to reach its full 100% output capacity during periods of peak wintertime heat losses or peak summertime heat gains.
- Internal heat gains from lighting and equipment may represent a significant part of the total building heat gain and be present all year round regardless of external weather conditions. For such buildings the cooling load may always be higher than that predicted by a simple sin curve.

Nevertheless, as the basis for a simple comparison exercise, it is considered that the general assumption of a sine curve relationship is sufficiently accurate to produce a meaningful comparison.

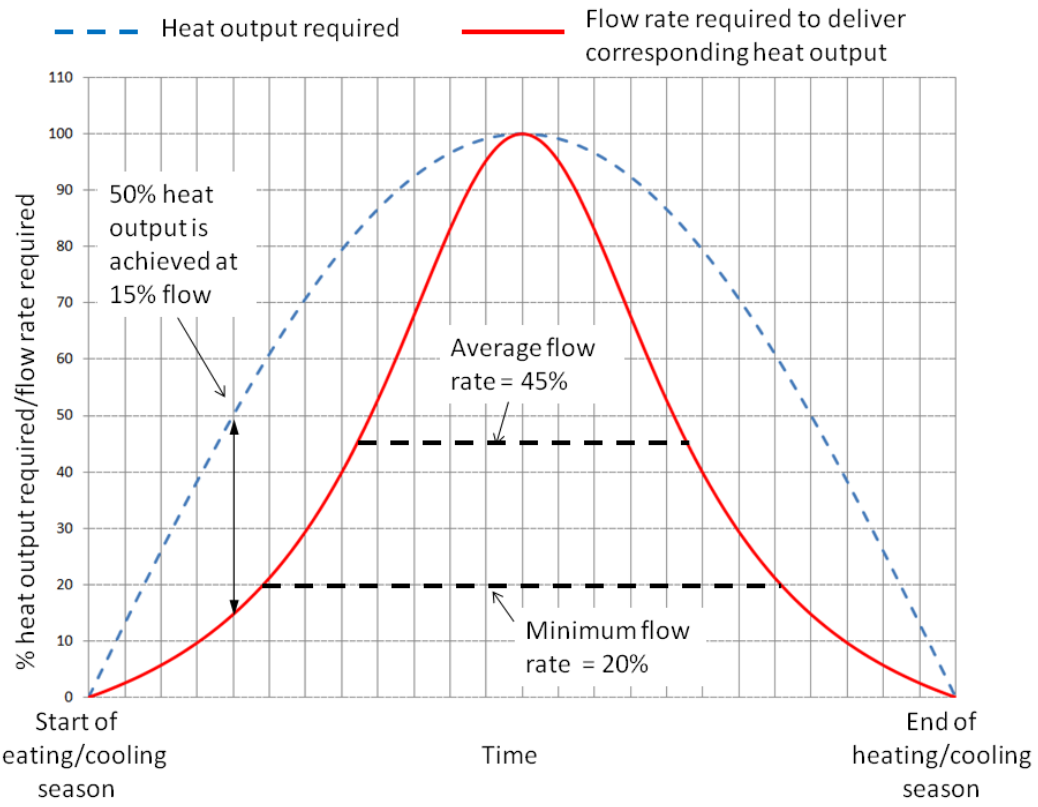
Following this assumption, it can be expected that the flow rate in a variable flow system will vary to match the sinusoidal variation in heating or cooling load. However, the variation in flow rate will not follow an identical pattern. This is because the heating or cooling output of a system is not proportional to the flow rate. Heating and cooling coils operating at close to full load tend to be relatively insensitive to changes in flow rate meaning that larger

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proportional reductions in flow are required to bring about a given reduction in heating or cooling output.

Taking this into account, Figures 2 and 3 show how the flow rates through the system would typically vary across heating or cooling seasons respectively. It can be seen from Figures 2 and 3 that if only 50% of the peak heating or cooling capacity is required then the flow rate can in theory drop to as little as 15% of its full load value for a heating system, or 33% for a chilled water system.

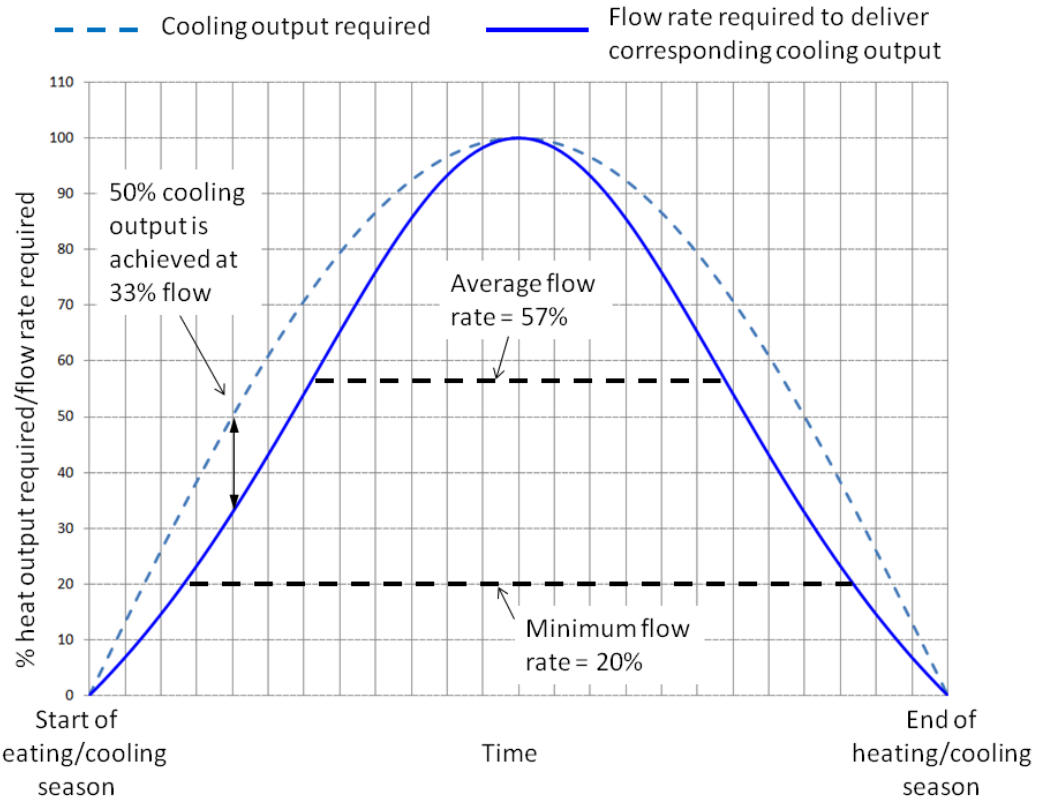
Figure 2 Typical pattern in heating system flow rate across a heating or cooling season



In order to estimate the average flow rate through the system across the entire heating or cooling season, account must be taken of the fact that no variable flow system will reduce its flow rate down to a value of zero. In order to prevent the risk of the pump pumping against a completely closed system, there must always be some pathway open to flow. For the purposes of this exercise it has been assumed that the reduction in flow rate will be not greater than 80%, i.e. a minimum flow rate equal to 20% of the full load value.

By breaking down the flow rate curves in Figure 2 and 3 into small sub-divisions, the average flow rate across the heating and cooling seasons can be estimated. As indicated on each graph the estimated average flow rates for heating and cooling seasons are 45% and 57% respectively.

Figure 3 Typical pattern in cooling system flow rate across a heating or cooling season



2.2.5 Variations in pump pressure

As can be seen from the previously stated equation for pump power, the power consumed by the pump is dependent on the system pressure loss as well as the flow rate. In theory, there is a square law relationship between flow rate and pressure loss such that the reduction in pressure is equal to the reduction in flow rate squared. Hence, any given drop in flow rate should give a much larger drop in pressure loss.

However, in practice this does not happen since in order to achieve the reduction in flow rate the system resistance increases due to the closure of control valves as they throttle the flows through terminal units. As a consequence, the reduction in pressure differential across the pump is largely determined by how pump speed is controlled. In many systems pump speed is controlled such that pump pressure is held constant under all operating conditions. This may reduce the energy saving potential of the pump but it also ensures that there will always be enough pressure in the system to satisfy demand.

Some engineers control pump speed such that the pressure differential is maintained at a point further out in the system. These systems give a better energy saving since the pressure generated by the pump is allowed to fall.

For the purpose of this research, two scenarios have been assumed as follows:

- pump pressure held constant under all flow conditions;
- pump pressure at the average system flow rate reduces to 30% of the pump pressure generated at full load.

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2.2.6 System running hours

The final variable that will influence pump life cycle energy consumption is the number of hours for which the pump will run over its operating life. It has been assumed that the pump will operate for 6 months of the year comprising around 4 weeks per month, 5 days per week and 12 hours per day. This gives a total running time of 1440 hours per year. The life expectancy of the system has been assumed as 15 years.

These values have deliberately been selected as minimum values. In practice, most systems would be expected to operate for longer hours than this. However, by selecting minimum durations as a starting point, the relevance of pump energy can be determined before the analysis is tested with longer running periods.

2.2.7 Summary of alternative system operating modes

The assumptions explained in the preceding section are summarised in Table 1. It can be seen that 5 different system operating modes are to be considered. The results contained in section 3 of this report provide outputs relative to each of these operating modes.

Table 1 Alternative system operating modes for example pipework system

Operating mode	Pump speed control	Type	Average flow rate %	Pump pressure at average flow rate %	Operating hours per year	Life expectancy
1	Constant flow	Heating and cooling	100	100	1440	15
2	Variable flow	Heating	45	100	1440	15
3	Variable flow	Heating	45	30	1440	15
4	Variable flow	Cooling	57	100	1440	15
5	Variable flow	Cooling	57	30	1440	15

2.3 EMBODIED ENERGY OF PIPEWORK

The embodied energy of a building material is the total primary energy consumed over its lifecycle. This normally includes extraction, manufacturing and transportation.

For the purpose of this research embodied energy figures have been sourced from the Inventory of Carbon and Energy (ICE) version 1.6a, downloaded from the University of Bath website. The ICE data was compiled by the Sustainable Energy Research Team (SERT), part of the Department of Mechanical Engineering.

From the ICE database, the embodied energy of steel pipe is 34.4 MJ/kg. This value is comparable to the embedded energy of virgin steel. Although the embodied energy associated with recycled steel is a lot less than this value, the ICE database indicates that recycling is not a typical manufacturing route.

For each of the pipe sizing calculations undertaken for the example system, the volume of steel in the pipework was calculated using the published figures for the internal and external dimensions of the pipes from BS 1387:1985 (EN 10255). The resulting volume of steel was then multiplied by a standard density figure of 7600 kg/m^3 to give the overall mass of steel in

the system. This mass of steel was finally multiplied by the embodied energy figure of 34.4 MJ/kg to give the overall embodied energy of the pipework. All results were expressed as kilowatt hours.

3 RESULTS

Appendix B contains the results of the pipe sizing exercise undertaken for the example system illustrated in Appendix A. Tables B1 to B14 show the pipe sizes selected and the pressure losses calculated for each section of the example pipework system.

Appendix C contains the results of the embodied energy calculations for each of the systems summarised in Appendix B. Tables C1 to C14 show the calculations of volume and mass of steel, and the embodied energy associated with its manufacture and transport.

Tables 2 to 6 below summarise the results and provide a complete calculation of lifecycle energy consumption for each of the operating modes summarised in Table 1 above.

Table 2 Lifecycle energy consumption for constant flow heating/cooling pipework system (operating mode 1)

Pipe sizing criteria (Pa/m upper limit)	Average flow rate (m3/s)*	Pump pressure (Pa)**	Pump efficiency	Average pump power (W)	Operating hours per year	Life expectancy (years)	Pump lifecycle energy (kWh)	Pipework embodied energy (kWh)	Total lifecycle energy (kWh)
50	0.200	25810	0.6	8606	1440	15	185,885	55,725	241,610
100	0.200	40746	0.6	13586	1440	15	293,457	48,961	342,418
150	0.200	56531	0.6	18849	1440	15	407,142	44,965	452,107
200	0.200	66372	0.6	22131	1440	15	478,024	42,977	521,001
250	0.200	77916	0.6	25980	1440	15	561,165	41,235	602,400
300	0.200	97327	0.6	32452	1440	15	700,966	39,816	740,782
350	0.200	115840	0.6	38625	1440	15	834,301	38,209	872,510
400	0.200	133929	0.6	44656	1440	15	964,577	36,665	1,001,242
450	0.200	150858	0.6	50301	1440	15	1,086,506	35,712	1,122,218
500	0.200	168972	0.6	56341	1440	15	1,216,963	34,537	1,251,499
550	0.200	194528	0.6	64862	1440	15	1,401,020	33,549	1,434,570
600	0.200	207405	0.6	69156	1440	15	1,493,767	33,249	1,527,016
650	0.200	219977	0.6	73348	1440	15	1,584,310	32,711	1,617,021
700	0.200	231510	0.6	77193	1440	15	1,667,373	32,469	1,699,842

* Average flow rate = 100% of full load design value

** Pump pressure = 100% full load design value

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Table 3 Lifecycle energy consumption for variable flow heating pipework system (operating mode 2)

Pipe sizing criteria (Pa/m upper limit)	Average flow rate (m3/s)*	Pump pressure (Pa)**	Pump efficiency	Average pump power (W)	Operating hours per year	Life expectancy (years)	Pump lifecycle energy (kWh)	Pipework embodied energy (kWh)	Total lifecycle energy (kWh)
50	0.090	25810	0.6	3873	1440	15	83,648	55,725	139,374
100	0.090	40746	0.6	6114	1440	15	132,056	48,961	181,016
150	0.090	56531	0.6	8482	1440	15	183,214	44,965	228,179
200	0.090	66372	0.6	9959	1440	15	215,111	42,977	258,088
250	0.090	77916	0.6	11691	1440	15	252,524	41,235	293,759
300	0.090	97327	0.6	14603	1440	15	315,435	39,816	355,251
350	0.090	115840	0.6	17381	1440	15	375,435	38,209	413,644
400	0.090	133929	0.6	20095	1440	15	434,060	36,665	470,724
450	0.090	150858	0.6	22636	1440	15	488,928	35,712	524,640
500	0.090	168972	0.6	25353	1440	15	547,633	34,537	582,170
550	0.090	194528	0.6	29188	1440	15	630,459	33,549	664,008
600	0.090	207405	0.6	31120	1440	15	672,195	33,249	705,444
650	0.090	219977	0.6	33006	1440	15	712,939	32,711	745,650
700	0.090	231510	0.6	34737	1440	15	750,318	32,469	782,787

* Average flow rate = 45% of full load design value

** Pump pressure = 100% full load design value

Table 4 Lifecycle energy consumption for variable flow heating pipework system (operating mode 3)

Pipe sizing criteria (Pa/m upper limit)	Average flow rate (m3/s)*	Pump pressure (Pa)**	Pump efficiency	Average pump power (W)	Operating hours per year	Life expectancy (years)	Pump lifecycle energy (kWh)	Pipework embodied energy (kWh)	Total lifecycle energy (kWh)
50	0.090	7743	0.6	1162	1440	15	25,094	55,725	80,820
100	0.090	12224	0.6	1834	1440	15	39,617	48,961	88,578
150	0.090	16959	0.6	2545	1440	15	54,964	44,965	99,929
200	0.090	19912	0.6	2988	1440	15	64,533	42,977	107,510
250	0.090	23375	0.6	3507	1440	15	75,757	41,235	116,992
300	0.090	29198	0.6	4381	1440	15	94,630	39,816	134,447
350	0.090	34752	0.6	5214	1440	15	112,631	38,209	150,840
400	0.090	40179	0.6	6029	1440	15	130,218	36,665	166,882
450	0.090	45257	0.6	6791	1440	15	146,678	35,712	182,390
500	0.090	50692	0.6	7606	1440	15	164,290	34,537	198,827
550	0.090	58358	0.6	8756	1440	15	189,138	33,549	222,687
600	0.090	62222	0.6	9336	1440	15	201,659	33,249	234,907
650	0.090	65993	0.6	9902	1440	15	213,882	32,711	246,593
700	0.090	69453	0.6	10421	1440	15	225,095	32,469	257,564

* Average flow rate = 45% of full load design value

** Pump pressure = 30% full load design value

Table 5 Lifecycle energy consumption for variable flow cooling pipework system (operating mode 4)

Pipe sizing criteria (Pa/m upper limit)	Average flow rate (m3/s)*	Pump pressure (Pa)**	Pump efficiency	Average pump power (W)	Operating hours per year	Life expectancy (years)	Pump lifecycle energy (kWh)	Pipework embodied energy (kWh)	Total lifecycle energy (kWh)
50	0.114	25810	0.6	4905	1440	15	105,954	55,725	161,680
100	0.114	40746	0.6	7744	1440	15	167,270	48,961	216,231
150	0.114	56531	0.6	10744	1440	15	232,071	44,965	277,036
200	0.114	66372	0.6	12615	1440	15	272,474	42,977	315,451
250	0.114	77916	0.6	14809	1440	15	319,864	41,235	361,099
300	0.114	97327	0.6	18498	1440	15	399,550	39,816	439,367
350	0.114	115840	0.6	22016	1440	15	475,552	38,209	513,760
400	0.114	133929	0.6	25454	1440	15	549,809	36,665	586,473
450	0.114	150858	0.6	28672	1440	15	619,308	35,712	655,020
500	0.114	168972	0.6	32114	1440	15	693,669	34,537	728,205
550	0.114	194528	0.6	36971	1440	15	798,581	33,549	832,131
600	0.114	207405	0.6	39419	1440	15	851,447	33,249	884,696
650	0.114	219977	0.6	41808	1440	15	903,057	32,711	935,768
700	0.114	231510	0.6	44000	1440	15	950,403	32,469	982,871

* Average flow rate = 57% of full load design value

** Pump pressure = 100% full load design value

Table 6 Lifecycle energy consumption for variable flow cooling pipework system (operating mode 5)

Pipe sizing criteria (Pa/m upper limit)	Average flow rate (m3/s)*	Pump pressure (Pa)**	Pump efficiency	Average pump power (W)	Operating hours per year	Life expectancy (years)	Pump lifecycle energy (kWh)	Pipework embodied energy (kWh)	Total lifecycle energy (kWh)
50	0.114	7743	0.6	1472	1440	15	31,786	55,725	87,512
100	0.114	12224	0.6	2323	1440	15	50,181	48,961	99,142
150	0.114	16959	0.6	3223	1440	15	69,621	44,965	114,586
200	0.114	19912	0.6	3784	1440	15	81,742	42,977	124,719
250	0.114	23375	0.6	4443	1440	15	95,959	41,235	137,194
300	0.114	29198	0.6	5549	1440	15	119,865	39,816	159,681
350	0.114	34752	0.6	6605	1440	15	142,665	38,209	180,874
400	0.114	40179	0.6	7636	1440	15	164,943	36,665	201,607
450	0.114	45257	0.6	8602	1440	15	185,792	35,712	221,505
500	0.114	50692	0.6	9634	1440	15	208,101	34,537	242,637
550	0.114	58358	0.6	11091	1440	15	239,574	33,549	273,124
600	0.114	62222	0.6	11826	1440	15	255,434	33,249	288,683
650	0.114	65993	0.6	12542	1440	15	270,917	32,711	303,628
700	0.114	69453	0.6	13200	1440	15	285,121	32,469	317,590

* Average flow rate = 57% of full load design value

** Pump pressure = 30% full load design value

3.1 ANALYSIS OF RESULTS

3.1.1 Pressure loss per metre pipe sizing criteria

The results indicated that the changes in pipe size brought about by varying the pressure drop per metre pipe sizing criterion have a far greater impact on the pump life cycle energy consumption than they do on the pipework embodied energy. This is illustrated graphically in Figures 4 and 5 (using the data from Tables 2-6 above). The graphs show the relationship between pump energy, pipework embodied energy and total energy consumption over the life

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of a constant volume system (operating mode 1) and a variable flow heating system (operating mode 2). It can be seen that pump lifecycle energy consumption contributes the largest proportion of total life cycle energy consumption across the entire range of pipe sizing criteria considered. The embodied energy of the pipework is relatively low in comparison.

For all of the operating modes selected, the total lifecycle energy consumption for the system is at its minimum when the lowest pressure drop per metre value is used for pipe sizing (i.e. 50 Pa/m). This indicates that in order to minimise the total lifecycle energy consumption of a re-circulating pipework system, it is better to install large low pressure loss pipes with a less powerful pump, rather than small high pressure loss pipes and a more powerful pump.

There is clearly scope to reduce the recommended pressure loss per metre pipe sizing value in order to reduce typical pump energy consumptions. However, any new recommendation must take into account the following considerations:

- Any recommendation to increase pipe sizes is likely to cause an increase in the installed cost of pipework systems.
- Larger pipes will also be more difficult to fit into congested services voids within buildings.
- Design engineers may be reluctant to size pipes below 100 Pa/m due to the very low velocities that could result, causing increased risk of dirt settlement and air locking.
- Standard line size orifice plate type flow measurement devices are designed to measure flow rates that correspond with pipes sized in the range 250-300 Pa/m. By reducing the limit, installers may need to install non line size devices, i.e. pipework would have to reduce in size at the flow measurement device.

Although significant on some projects, these issues should not represent a barrier to putting forward a clear recommendation to designers. It is the author's view that an immediate reduction in the recommended maximum pressure drop per metre limit from 300 Pa/m to 200 Pa/m would result in a 30% pump energy saving for new installations without incurring any significant problems. It is recommended that this idea is put to stakeholder companies for their opinion.

Figure 4 Total life cycle energy consumption for a constant flow system

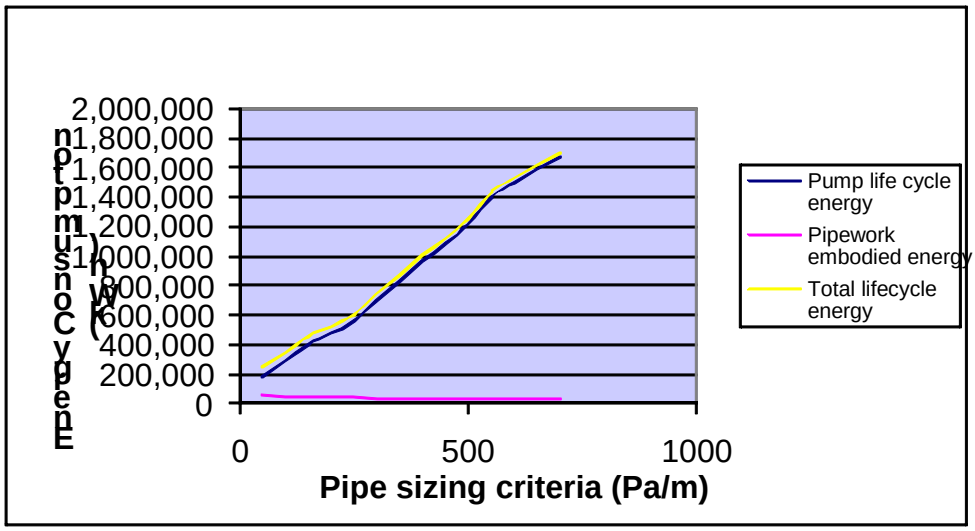
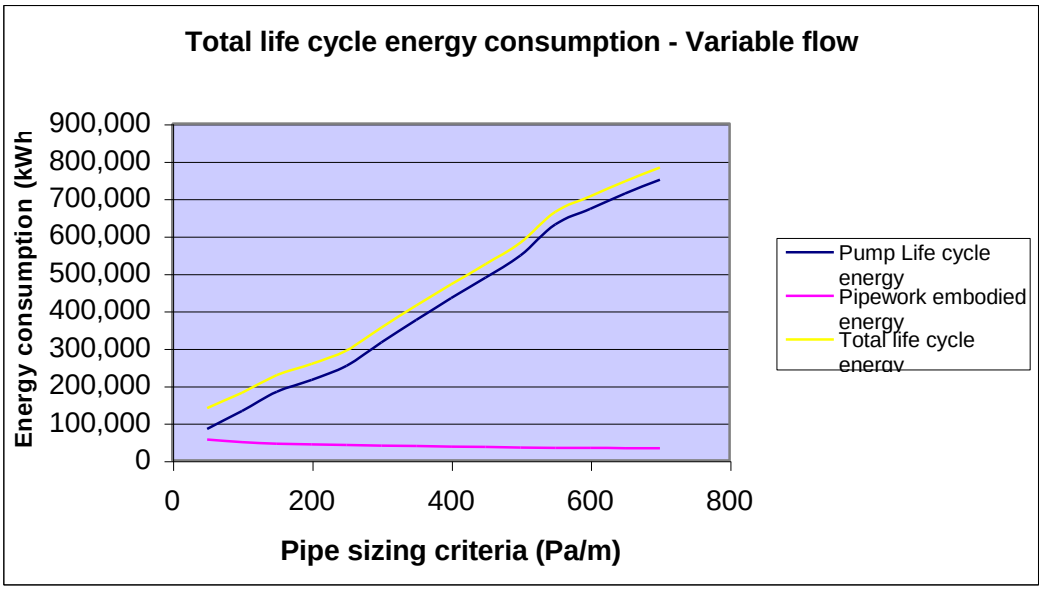


Figure 5 Total life cycle energy consumption for a variable flow system



3.1.2 Variable speed pumping

Figures 6 and 7 show the total life cycle energy consumption for heating and cooling systems operating at constant flow and variable flow under different methods of pump speed control. The flow conditions for each system are as indicated in Table 1.

It can be seen that the variable speed pumping is able to achieve a significant reduction in pump energy consumption, and that the greatest savings occur when pump speed is controlled such that the pump pressure is permitted to fall to as low as value as possible.

Table 7 shows a comparison between the average pump powers predicted for each of the operating modes when pipes are sized within an upper limit of 300 Pa/m (a typical upper limit value used by design engineers on existing projects). The results show that reductions in pump energy consumption of up to 86.5% for heating and 82.9% for cooling can be achieved when the pump is controlled such that its speed varies in response to the heating or cooling demand in the building. The savings are largest when both pump flow rate and pressure are permitted to reduce to around 30% of the full load pump pressure (operating modes 3 and 5).

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Figure 6 **Total life cycle energy consumption for constant flow and variable flow heating system**

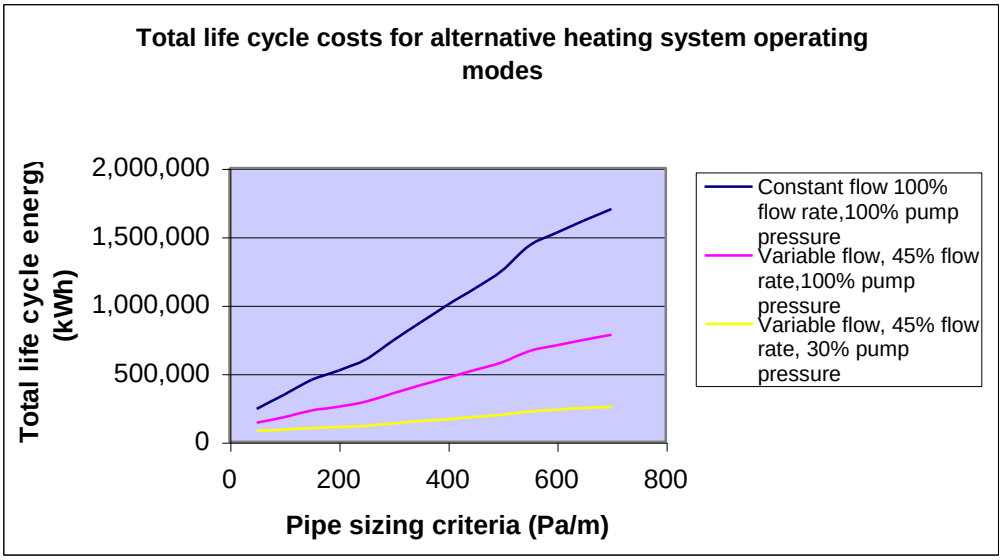
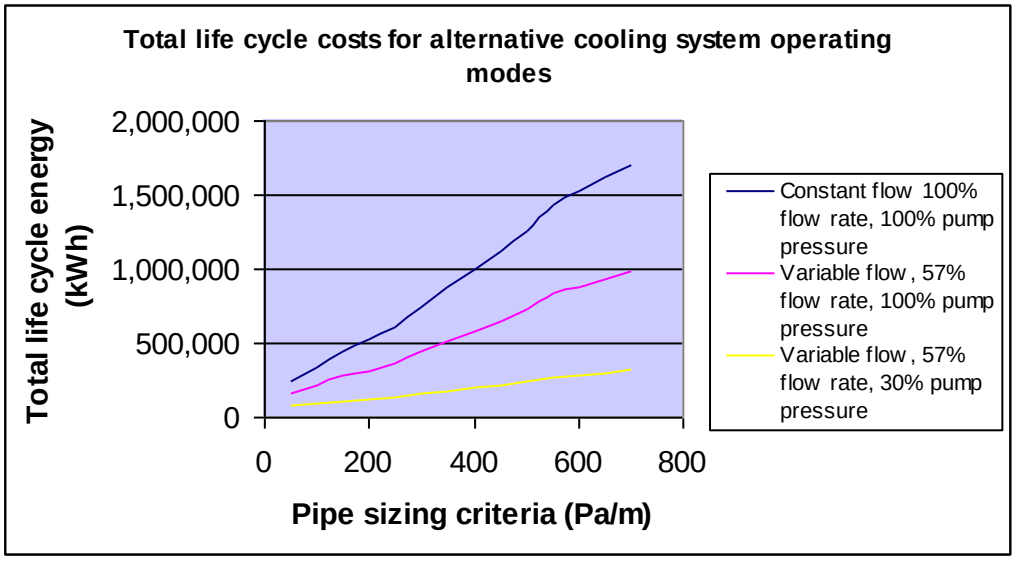


Figure 7 **Total Life cycle energy consumption for constant flow and variable flow cooling system**



These savings are due to the cube law relationship between flow rate and pump power. For a given percentage reduction in flow rate, the pump power required to circulate the water has the potential to reduce by that percentage cubed. (Hence a 50% reduction in flow is accompanied by a reduction of up to 87.5% in pump power, depending on how pump speed is controlled.)

Table 7 Comparison between estimated pump powers for stated operating modes

Operating mode	Average flow rate (m3/s)	Pump pressure (Pa)	Pump efficiency	Average pump power (W)	%
Constant flow, constant pressure, (heating & cooling)	0.200	97327	0.6	32452	100.0
Average flow 45%, average pump pressure 100% (heating only)	0.090	97327	0.6	14603	45.0
Average flow 45%, average pump pressure 30% (heating only)	0.090	29198	0.6	4381	13.5
Average flow 57%, average pump pressure 100% (cooling only)	0.114	97327	0.6	18498	57.0
Average flow 57%, average pump pressure 30% (cooling only)	0.114	29198	0.6	5549	17.1

It can be seen that variable speed pumping and its method of control has a far larger impact on pump life cycle energy consumption than the choice of pipe sizing criteria. Nevertheless, pipe sizing criterion is still of significance, particularly since not all systems will vary in load to the degree assumed for the purposes of this report.

3.1.3 Contribution of fittings, valves and terminal units

Table 8 provides a breakdown of pipe pressure losses and fittings pressure losses for each of the sets of pipe sizing results tabulated in Appendix B. Figures 8 and 9 show the main trends as graphs.

Table 8 Comparison between pipe pressure losses and losses due to fittings

Pipe sizing criteria (Pa/m upper limit)	Pipe losses (Pa)	Pipe losses %	Fittings losses (Pa)	Fitting losses %	Total losses (Pa)
50	11588	45%	14221	55%	25810
100	22159	54%	18586	46%	40746
150	33797	60%	22733	40%	56531
200	41346	62%	25026	38%	66372
250	49570	64%	28347	36%	77916
300	60626	62%	36701	38%	97327
350	73791	64%	42050	36%	115840
400	86066	64%	47862	36%	133929
450	97440	65%	53419	35%	150858
500	109377	65%	59595	35%	168972
550	131599	63%	75806	37%	207405
600	131599	63%	75806	37%	207405
650	141612	64%	78365	36%	219977
700	146807	63%	84704	37%	231510

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Figure 8 shows the change in pipe and fittings pressure losses across the range of pipe sizing criteria. Figure 9 shows how the relative proportions of pipe and fitting losses vary across the same range.

It can be seen from Figure 8 that as the pipe sizing criteria is increased, both pipe and fitting pressure losses increase. Over the pipe sizing criteria range, the pipe losses always exceed the fitting losses. It can be seen from Figure 9 that as the pipe sizing criterion reduces from about 250Pa/m, the proportion of system pressure loss due to pipes reduces whilst the proportion due to fittings increases. This is largely due to the allowance of a fixed 10 kPa pressure loss for valves and terminal unit which has been included within the fittings pressure drop figures. In all systems, these pressure losses remain approximately constant regardless of changes in design flow rate. It can be seen that for a system sized to a limiting pressure loss of 200Pa/m, out of the fittings loss of 25.026kPa, 10kPa is due to the allowance for valves and terminal unit. Beyond the pipe sizing criteria of 250Pa/m, there is no change in the pipe and fitting losses as a proportion of the total system losses.

It can be concluded that if the limiting pressure loss per metre pipe sizing value is lowered from around 250Pa/m, the significance of fittings increases suggesting that a further significant reduction in pump power could be gained by finding ways to minimise pressure losses through fittings, valves and terminal units.

Figure 8 Pipe and fitting pressure losses

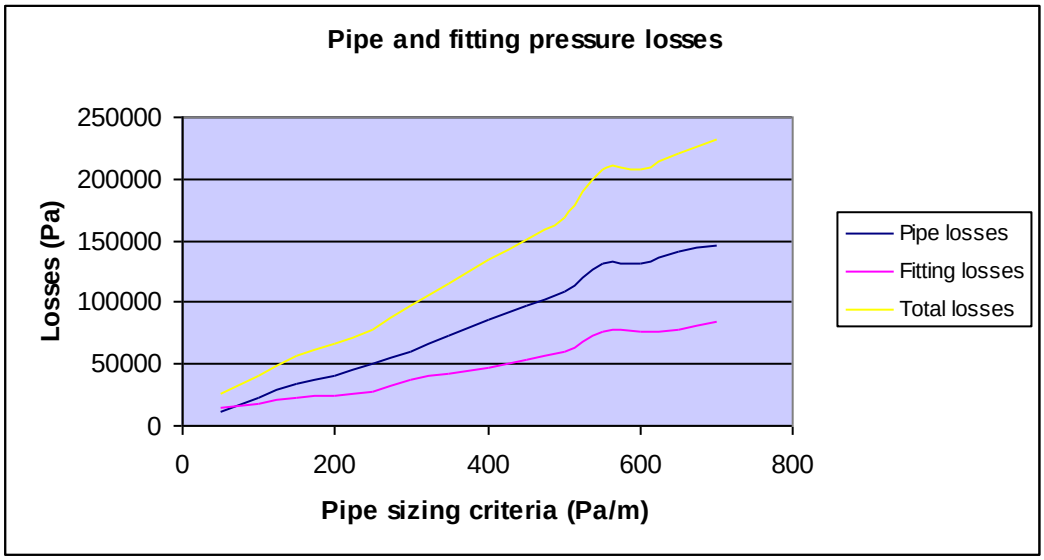
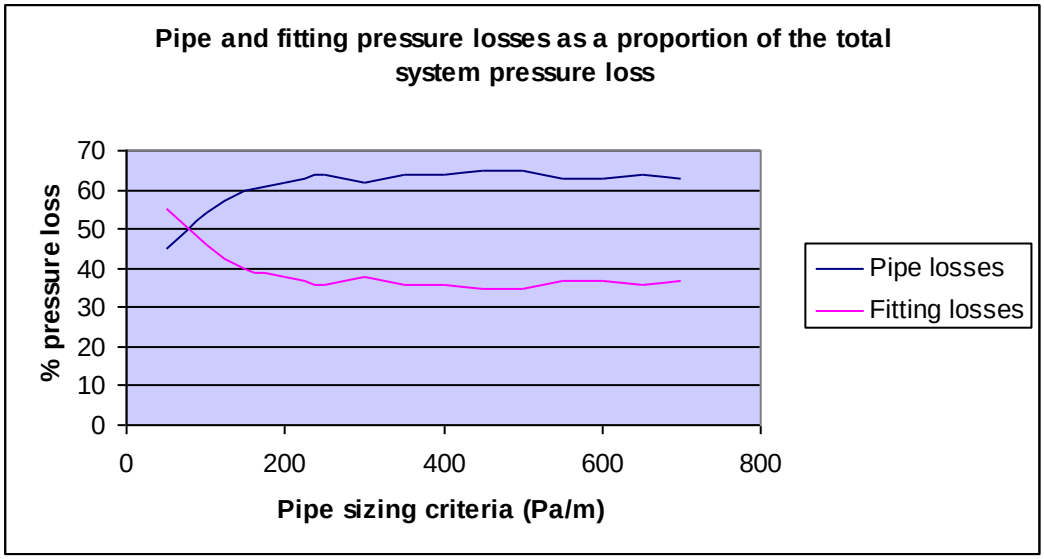


Figure 9 Variation of the pipe and fitting losses as proportion of the total system losses



3.1.4 Alternative materials

The use of copper or plastic pipe instead of steel was considered. The embodied energy incorporated in the example system when sized within a limiting pressure loss of 300Pa/m was re-evaluated assuming the embodied energy and density values for copper and plastic. A summary of the findings is show in Table 9.

Table 9 Comparison between lifecycle energy consumptions for steel, copper and plastic pipework

Operating mode	Total lifecycle energy (kWh)				
	Steel	Copper	Variation	Plastic	Variation
Constant flow, constant pressure, (heating & cooling)	740,782	793,725	107%	712,837	96%
Average flow 45%, average pump pressure 100% (heating only)	355,251	408,194	115%	327,306	92%
Average flow 45%, average pump pressure 30% (heating only)	134,447	187,390	140%	106,502	80%
Average flow 57%, average pump pressure 100% (cooling only)	439,367	492,310	112%	411,422	94%
Average flow 57%, average pump pressure 30% (cooling only)	159,681	212,624	134%	131,736	83%

For copper, the embodied energy values published in the ICE database vary in the range 40 – 70 MJ/kg. This is attributable to the variety of sources from which copper is derived. The density of copper is also higher than that for steel at 8930kg/m^3 compared to 7600kg/m^3. Hence, it can be shown that the embodied energy for a given volume of copper is approximately 2.4 times as much as for the same volume of steel (i.e. 70 MJ/kg times 8930 kg/m^3 compared to 34.4 MJ/kg times 7600 kg/m^3). It can therefore be concluded that steel is a more energy efficient material than copper for pipework systems. When pump energy is taken into account, the overall increases in lifecycle energy attributable to the use of copper pipe would be as indicated in Table 9.

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For plastic pipe, the embodied energy value published in the ICE database of general plastics is 80MJ/kg. However, the density of plastic is lower than that for steel at around 1000kg/m^3. Hence, it can be shown that the embodied energy for a given volume of plastic is approximately 0.3 times that for the same volume of steel (i.e. 80 MJ/kg times 1000 kg/m^3 compared to 34.4 MJ/kg times 7600 kg/m^3). It can therefore be concluded that plastic is a more energy efficient material than steel for pipework systems. When pump energy is taken into account, the overall reductions in lifecycle energy attributable to the use of plastic pipe would be as indicated in Table 9.

It can be seen that savings of 17-20% in lifecycle energy consumption are achievable by using plastic pipework instead of steel. The percentage savings are largest in systems where pump speed is variable, since pipework embodied energy represents a larger proportion of the total lifecycle energy consumption in these systems.

Although these findings do not alter the preceding conclusion that it is better to minimise pump energy than pipe sizes, the results do suggest that plastic pipework can provide a significant reduction in lifecycle energy compared to steel. This finding should be considered in subsequent stages of the research.

3.1.5 Operating hours and life expectancy

The analysis of life cycle energy consumption assumes 1440 operating hours per year and a life expectancy of 15 years. These values are considered to be minimums. In practice it is likely that most installed heating and cooling systems will operate for a greater number of hours per year and will have a life expectancy in excess of 15 years. Where this is the case, the life cycle pump energy consumption figures will increase whilst the pipework embodied energy figures will remain constant. This will further enforce the conclusions of this research that it is better, in terms of life cycle energy consumption, to minimise pump power by sizing pipes with as low as possible pressure losses.

4 DEVELOP RANGE OF FURTHER OPTIONS

This section of the report develops a range of further options that might be considered in Phase 2 of the project. These include:

- Detailed modelling of system performance
- Establishing design guidance for increasing temperature differentials
- Development of key findings

4.1 DETAILED MODELLING OF SYSTEM PERFORMANCE

The objective of this work will be to determine the most energy efficient design solutions for re-circulating heating and chilled water systems. In simple terms, different design solutions will be assessed to determine which of them achieves the lowest pump energy consumption in practice.

Method

The various design solutions described in different industry design guides will be modelled and assessed. Drawing on the advice given in CIBSE Knowledge Series Guide KS7 and from known product solutions available from valve suppliers, the various system solutions to be modelled are anticipated to include the following:

- A standard constant flow system with 3 or 4 port diverting valves
- A variable flow system using self-balancing arrangements with reverse return layouts
- A variable flow system using differential pressure control valves on sub-branches
- A variable flow system using pressure independent control valves
- A variable flow system using centralised valve modules

An example layout of terminal units shall be developed that is typical of a medium scale multi-storey office development, i.e. up to 200 fan coil units spread evenly over 5 floors. For each of the pipe system design solutions identified above, a typical pipework layout will be developed, sized and measured. Based on a calculation of pressure loss for each alternative, a notional pump will be sized and the resulting pump energy consumption determined.

The variations in pump energy consumption due to variable speed pumping will also be taken into account by selecting a fixed load profile for the building and applying this to the results for each option.

The results will be compared to show the relative energy consumption values for each solution. This comparison will be used as the basis for a set of design recommendations for engineers regarding optimum design layouts for re-circulating pipework systems.

The findings of work will be written up as an interim report detailing the method, findings and conclusions.

4.2 DESIGN GUIDANCE FOR INCREASING TEMPERATURE DIFFERENTIALS

The objective of this work package is to establish design guidance that encourages larger design temperature differentials in heating systems. This would achieve the benefit of lower pump energy consumptions, plus the additional benefits of higher efficiencies from

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condensing boilers (due to the reduced return temperatures) and more opportunities for low energy heat sources such as heat pumps and solar energy.

Method

Alternative circuit design solutions shall be sourced drawing on the experience of equipment manufacturers and engineers. Since other European countries appear to have a greater body of experience in the design of systems incorporating condensing boilers, heat pumps and combined heat and power (CHP) solutions, reference will be made to the procedures and design guides that are used in those countries. Following the Stakeholders meeting, a number of sources in Denmark and Germany have been identified for this purpose, including boiler manufacturers and CHP suppliers. These organisations will be approached in order to obtain advice and expertise.

Having established alternative solutions for piping heating systems, the methods proposed will be analysed to ensure that the methods proposed are compatible with UK practices. The output will be a set of design guidance explaining how to configure system designs to optimise the energy performance of central plant items such as condensing boilers.

The findings of the work package will be written up as an interim report detailing the method, findings and conclusions.

4.3 DEVELOPMENT OF KEY FINDINGS

The objective of this work will be to develop the key findings and recommendation from preceding work packages into a design guide suitable for issue to industry. The guide will draw on the background research that has led to the recommendations, but will primarily focus on the recommendations themselves. The draft guide will be circulated to industry stakeholders to obtain their input.

A final draft of the guide will then be prepared ready for launch to industry.

5 CONCLUSIONS

Based on the results preceding findings of this report the following conclusions can be drawn.

1. Varying the pressure drop per metre pipe sizing criterion has a greater impact on pump life cycle energy consumption than on the embodied energy of installed pipework. Only when the limiting pressure drop per metre sizing criterion is less than 50Pa/m does the increase in pipework embodied energy become a significant contributor to system lifecycle energy consumption. This conclusion applies:

    - to all heating and cooling water system design and control options, i.e. whether they are constant flow systems that hold flow constant or variable flow systems in which pump speed is varied to match the demand for heating or cooling.

    - whether the system pipework is constructed from steel, copper or plastic.

2. Following from the previous item, it can be concluded that in order to minimise the total lifecycle energy consumption of a re-circulating pipework system, it is better to install large low pressure loss pipes with a less powerful pump, rather than small high pressure loss pipes and a more powerful pump.

3. However, a recommendation to size pipes at 50 Pa/m or less would significantly increase pipework costs, make it more difficult to fit pipes into buildings, and would cause problems of flow measurement. It is therefore proposed that the recommended maximum pressure drop per metre limit of 300 Pa/m be reduced to 200 Pa/m. This would result in a 30% pump energy saving for new installations operating at full load, without incurring the aforementioned problems for designers and installers.

4. It has been shown that if the limiting pressure loss per metre pipe sizing value is lowered to 200 Pa/m, the proportion of system pressure losses due to fittings and components such as elbows, tees and valves increases. This suggests that a further significant reduction in pump power could be gained by finding ways to minimise pressure losses through fittings, valves and terminal units. This issue should be addressed at subsequent stages of the research.

5. The findings show that energy savings of up to 86.5% for heating and 82.9% for cooling can be achieved when the pump is controlled such that its speed varies in response to the heating or cooling demand in the building. These savings are achievable when the building has a heating or cooling load pattern that matches outside temperature conditions, and pump flow rate is permitted to reduce to a minimum of 20% of the full load design value and pump pressure is permitted to reduce to around 30% of the full load pump pressure. It can be concluded that by ensuring that all installed systems have pumps that vary their speed is critical to reducing pump energy consumption. This issue should be addressed at subsequent stages of the research.

6. The findings show that that savings of 17-20% in lifecycle energy consumption are achievable by using plastic pipework instead of steel. The percentage savings are largest in systems where pump speed is variable, since pipework embodied energy represents a larger proportion of the total lifecycle energy consumption in these systems. This finding should be considered in subsequent stages of the research.

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Appendix: A
Schematic Diagram of Example System

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Appendix: B
Pipe Sizing and Pressure Loss Calculation Results

Table B1: Pipe sizes selected based on limiting pressure loss of 50Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	400	398.4	1.605	47	1287		0.15	280	193	473
B-C	6	100	300	315.9	1.276	40	814	2	1.61	240	1310	1551
C-D	6	90	300	315.9	1.148	33	659		0.21	197	138	336
D-E	6	80	300	315.9	1.021	26	521		0.21	158	109	268
E-F	6	70	250	265.8	1.262	48	796		0.21	290	167	457
F-G	6	60	250	265.8	1.081	36	585		0.21	217	123	340
G-H	6	50	250	265.8	0.901	26	406		0.21	155	85	240
H-I	6	40	250	265.8	0.721	17	260		0.21	102	55	157
I-J	6	30	200	211.9	0.851	31	362		0.2	183	72	255
J-K	6	20	200	211.9	0.567	14	161		0.15	87	24	111
K-L	6	10	125	128.9	0.766	46	294	2	1.51	277	443	721
L-M	6	9.8	125	128.9	0.751	45	282		0.11	267	31	298
M-N	6	9.6	125	128.9	0.736	43	271		0.11	257	30	287
N-O	6	9.4	125	128.9	0.720	41	259		0.11	247	29	276
O-P	6	9.2	125	128.9	0.705	40	249		0.11	238	27	265
P-Q	6	9	125	128.9	0.690	38	238		0.11	228	26	255
Q-R	6	8.8	125	128.9	0.674	37	227		0.11	219	25	244
R-S	6	8.6	125	128.9	0.659	35	217		0.11	210	24	234
S-T	6	8.4	125	128.9	0.644	34	207		0.11	201	23	224
T-U	6	8.2	125	128.9	0.628	32	197		0.11	193	22	214
U-V	6	8	125	128.9	0.613	31	188		0.11	184	21	205
V-W	6	7.8	125	128.9	0.598	29	179		0.11	176	20	195
W-X	6	7.6	125	128.9	0.582	28	170		0.11	168	19	186
X-Y	6	7.4	125	128.9	0.567	27	161		0.11	160	18	177
Y-Z	6	7.2	125	128.9	0.552	25	152		0.11	152	17	169
Z-AB	6	7	125	128.9	0.537	24	144		0.11	144	16	160
AB-AC	6	6.8	125	128.9	0.521	23	136		0.11	137	15	152
AC-AD	6	6.6	125	128.9	0.506	22	128		0.11	130	14	144
AD-AE	6	6.4	125	128.9	0.491	20	120		0.11	123	13	136
AE-AF	6	6.2	125	128.9	0.475	19	113		0.11	116	12	128
AF-AG	6	6	125	128.9	0.460	18	106		0.11	109	12	121
AG-AH	6	5.8	100	103.3	0.692	50	239		0.11	302	26	328
AH-AI	6	5.6	100	103.3	0.668	47	223		0.11	283	25	308
AI-AJ	6	5.4	100	103.3	0.644	44	208		0.11	265	23	288
AJ-AK	6	5.2	100	103.3	0.621	41	192		0.11	247	21	269
AK-AL	6	5	100	103.3	0.597	38	178		0.11	230	20	250
AL-AM	6	4.8	100	103.3	0.573	36	164		0.11	214	18	232
AM-AN	6	4.6	100	103.3	0.549	33	151		0.11	198	17	215
AN-AO	6	4.4	100	103.3	0.525	30	138		0.11	183	15	198
AO-AP	6	4.2	100	103.3	0.501	28	126		0.11	168	14	182
AP-AQ	6	4	100	103.3	0.477	26	114		0.11	154	13	166
AQ-AR	6	3.8	100	103.3	0.453	23	103		0.11	140	11	151
AR-AS	6	3.6	100	103.3	0.430	21	92		0.11	127	10	137
AS-AT	6	3.4	100	103.3	0.406	19	82		0.11	115	9	124
AT-AU	6	3.2	100	103.3	0.382	17	73		0.11	103	8	111
AU-AV	6	3	100	103.3	0.358	15	64		0.11	92	7	99
AV-AW	6	2.8	80	78.8	0.574	50	165		0.11	301	18	319
AW-AX	6	2.6	80	78.8	0.533	44	142		0.11	263	16	279
AX-AY	6	2.4	80	78.8	0.492	38	121		0.11	228	13	241
AY-AZ	6	2.2	80	78.8	0.451	32	102		0.11	195	11	206
AZ-BA	6	2	80	78.8	0.410	27	84		0.11	164	9	173
BA-BB	6	1.8	65	67	0.511	50	130		0.21	298	27	326
BB-BC	6	1.6	65	67	0.454	40	103		0.21	241	22	263
BC-BD	6	1.4	65	67	0.397	32	79		0.21	190	17	206
BD-BE	6	1.2	65	67	0.340	24	58		0.21	144	12	156
BE-BF	6	1	65	67	0.284	17	40		0.21	104	8	113
BF-BG	6	0.8	50	51.3	0.387	42	75		3.16	254	237	491
BG-BH	6	0.6	50	51.3	0.290	25	42		2.77	153	117	269
BH-BI	6	0.4	40	40.4	0.312	39	49		2.2	236	107	343
BI-BJ	6	0.2	32	34.5	0.214	25	23	8	10.4	150	10238	10388
									TOTALS:	11588	14221	25810

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Table B2: Pipe sizes selected based on limiting pressure loss of 100Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	350	347.6	2.108	92	2221		0.15	554	333	887
B-C	6	100	250	265.8	1.802	95	1624	2	1.61	568	2615	3182
C-D	6	90	250	265.8	1.622	78	1315		0.21	465	276	741
D-E	6	80	250	265.8	1.442	62	1039		0.21	372	218	591
E-F	6	70	250	265.8	1.262	48	796		0.21	290	167	457
F-G	6	60	250	265.8	1.081	36	585		0.21	217	123	340
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	200	211.9	1.134	52	643		0.21	313	135	448
I-J	6	30	200	211.9	0.851	31	362		0.2	183	72	255
J-K	6	20	150	154.4	1.068	68	571		0.15	411	86	496
K-L	6	10	125	128.9	0.766	46	294	2	1.51	277	443	721
L-M	6	9.8	125	128.9	0.751	45	282		0.11	267	31	298
M-N	6	9.6	125	128.9	0.736	43	271		0.11	257	30	287
N-O	6	9.4	125	128.9	0.720	41	259		0.11	247	29	276
O-P	6	9.2	125	128.9	0.705	40	249		0.11	238	27	265
P-Q	6	9	125	128.9	0.690	38	238		0.11	228	26	255
Q-R	6	8.8	125	128.9	0.674	37	227		0.11	219	25	244
R-S	6	8.6	125	128.9	0.659	35	217		0.11	210	24	234
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	100	103.3	0.955	91	456		0.11	546	50	596
V-W	6	7.8	100	103.3	0.931	87	433		0.11	521	48	569
W-X	6	7.6	100	103.3	0.907	83	411		0.11	496	45	542
X-Y	6	7.4	100	103.3	0.883	79	390		0.11	473	43	516
Y-Z	6	7.2	100	103.3	0.859	75	369		0.11	449	41	490
Z-AB	6	7	100	103.3	0.835	71	349		0.11	427	38	465
AB-AC	6	6.8	100	103.3	0.812	67	329		0.11	404	36	441
AC-AD	6	6.6	100	103.3	0.788	64	310		0.11	383	34	417
AD-AE	6	6.4	100	103.3	0.764	60	292		0.11	362	32	394
AE-AF	6	6.2	100	103.3	0.740	57	274		0.11	341	30	371
AF-AG	6	6	100	103.3	0.716	54	256		0.11	321	28	350
AG-AH	6	5.8	100	103.3	0.692	50	239		0.11	302	26	328
AH-AI	6	5.6	100	103.3	0.668	47	223		0.11	283	25	308
AI-AJ	6	5.4	100	103.3	0.644	44	208		0.11	265	23	288
AJ-AK	6	5.2	100	103.3	0.621	41	192		0.11	247	21	269
AK-AL	6	5	100	103.3	0.597	38	178		0.11	230	20	250
AL-AM	6	4.8	100	103.3	0.573	36	164		0.11	214	18	232
AM-AN	6	4.6	100	103.3	0.549	33	151		0.11	198	17	215
AN-AO	6	4.4	100	103.3	0.525	30	138		0.11	183	15	198
AO-AP	6	4.2	100	103.3	0.501	28	126		0.11	168	14	182
AP-AQ	6	4	80	78.8	0.820	96	336		0.11	577	37	614
AQ-AR	6	3.8	80	78.8	0.779	88	304		0.11	525	33	559
AR-AS	6	3.6	80	78.8	0.738	79	272		0.11	476	30	506
AS-AT	6	3.4	80	78.8	0.697	71	243		0.11	428	27	455
AT-AU	6	3.2	80	78.8	0.656	64	215		0.11	384	24	407
AU-AV	6	3	80	78.8	0.615	57	189		0.11	341	21	362
AV-AW	6	2.8	80	78.8	0.574	50	165		0.11	301	18	319
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	65	67	0.681	84	232		0.11	502	25	528
AY-AZ	6	2.2	65	67	0.624	71	195		0.11	429	21	450
AZ-BA	6	2	65	67	0.567	60	161		0.11	361	18	378
BA-BB	6	1.8	65	67	0.511	50	130		0.21	298	27	326
BB-BC	6	1.6	65	67	0.454	40	103		0.21	241	22	263
BC-BD	6	1.4	65	67	0.397	32	79		0.21	190	17	206
BD-BE	6	1.2	50	51.3	0.581	88	169		3.62	526	610	1136
BE-BF	6	1	50	51.3	0.484	63	117		3.62	379	424	803
BF-BG	6	0.8	50	51.3	0.387	42	75		3.16	254	237	491
BG-BH	6	0.6	40	40.4	0.468	81	110		2.77	484	303	787
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	25	25.8	0.383	100	73	8	12	603	10878	11481
									TOTALS:	22159	18586	40746

Table B3: Pipe sizes selected based on limiting pressure loss of 150Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	300	315.9	2.552	149	3256		0.15	894	488	1383
B-C	6	100	250	265.8	1.802	95	1624	2	1.61	568	2615	3182
C-D	6	90	250	265.8	1.622	78	1315		0.21	465	276	741
D-E	6	80	250	265.8	1.442	62	1039		0.21	372	218	591
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	200	211.9	1.134	52	643		0.21	313	135	448
I-J	6	30	150	154.4	1.603	146	1284		0.2	877	257	1134
J-K	6	20	150	154.4	1.068	68	571		0.15	411	86	496
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	100	103.3	1.026	104	527		0.11	624	58	682
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	100	103.3	0.955	91	456		0.11	546	50	596
V-W	6	7.8	100	103.3	0.931	87	433		0.11	521	48	569
W-X	6	7.6	100	103.3	0.907	83	411		0.11	496	45	542
X-Y	6	7.4	100	103.3	0.883	79	390		0.11	473	43	516
Y-Z	6	7.2	100	103.3	0.859	75	369		0.11	449	41	490
Z-AB	6	7	100	103.3	0.835	71	349		0.11	427	38	465
AB-AC	6	6.8	100	103.3	0.812	67	329		0.11	404	36	441
AC-AD	6	6.6	100	103.3	0.788	64	310		0.11	383	34	417
AD-AE	6	6.4	100	103.3	0.764	60	292		0.11	362	32	394
AE-AF	6	6.2	100	103.3	0.740	57	274		0.11	341	30	371
AF-AG	6	6	100	103.3	0.716	54	256		0.11	321	28	350
AG-AH	6	5.8	100	103.3	0.692	50	239		0.11	302	26	328
AH-AI	6	5.6	100	103.3	0.668	47	223		0.11	283	25	308
AI-AJ	6	5.4	100	103.3	0.644	44	208		0.11	265	23	288
AJ-AK	6	5.2	100	103.3	0.621	41	192		0.11	247	21	269
AK-AL	6	5	80	78.8	1.025	145	526		0.11	871	58	928
AL-AM	6	4.8	80	78.8	0.984	135	484		0.11	807	53	861
AM-AN	6	4.6	80	78.8	0.943	124	445		0.11	746	49	795
AN-AO	6	4.4	80	78.8	0.902	115	407		0.11	688	45	732
AO-AP	6	4.2	80	78.8	0.861	105	371		0.11	631	41	672
AP-AQ	6	4	80	78.8	0.820	96	336		0.11	577	37	614
AQ-AR	6	3.8	80	78.8	0.779	88	304		0.11	525	33	559
AR-AS	6	3.6	80	78.8	0.738	79	272		0.11	476	30	506
AS-AT	6	3.4	80	78.8	0.697	71	243		0.11	428	27	455
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	65	67	0.681	84	232		0.11	502	25	528
AY-AZ	6	2.2	65	67	0.624	71	195		0.11	429	21	450
AZ-BA	6	2	65	67	0.567	60	161		0.11	361	18	378
BA-BB	6	1.8	65	67	0.511	50	130		0.21	298	27	326
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	50	51.3	0.677	116	229		3.62	696	830	1526
BD-BE	6	1.2	50	51.3	0.581	88	169		3.62	526	610	1136
BE-BF	6	1	50	51.3	0.484	63	117		3.62	379	424	803
BF-BG	6	0.8	40	40.4	0.624	135	195		3.16	811	615	1427
BG-BH	6	0.6	40	40.4	0.468	81	110		2.77	484	303	787
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	25	25.8	0.383	100	73	8	12	603	10878	11481
									TOTALS:	33797	22733	56531

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Table B4: Pipe sizes selected based on limiting pressure loss of 200Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	300	315.9	2.552	149	3256		0.15	894	488	1383
B-C	6	100	250	265.8	1.802	95	1624	2	1.61	568	2615	3182
C-D	6	90	250	265.8	1.622	78	1315		0.21	465	276	741
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	200	211.9	1.134	52	643		0.21	313	135	448
I-J	6	30	150	154.4	1.603	146	1284		0.2	877	257	1134
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	100	103.3	1.026	104	527		0.11	624	58	682
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	100	103.3	0.955	91	456		0.11	546	50	596
V-W	6	7.8	100	103.3	0.931	87	433		0.11	521	48	569
W-X	6	7.6	100	103.3	0.907	83	411		0.11	496	45	542
X-Y	6	7.4	100	103.3	0.883	79	390		0.11	473	43	516
Y-Z	6	7.2	100	103.3	0.859	75	369		0.11	449	41	490
Z-AB	6	7	100	103.3	0.835	71	349		0.11	427	38	465
AB-AC	6	6.8	100	103.3	0.812	67	329		0.11	404	36	441
AC-AD	6	6.6	100	103.3	0.788	64	310		0.11	383	34	417
AD-AE	6	6.4	100	103.3	0.764	60	292		0.11	362	32	394
AE-AF	6	6.2	100	103.3	0.740	57	274		0.11	341	30	371
AF-AG	6	6	100	103.3	0.716	54	256		0.11	321	28	350
AG-AH	6	5.8	80	78.8	1.189	191	707		0.11	1146	78	1224
AH-AI	6	5.6	80	78.8	1.148	179	659		0.11	1074	73	1147
AI-AJ	6	5.4	80	78.8	1.107	167	613		0.11	1004	67	1071
AJ-AK	6	5.2	80	78.8	1.066	156	568		0.11	936	63	999
AK-AL	6	5	80	78.8	1.025	145	526		0.11	871	58	928
AL-AM	6	4.8	80	78.8	0.984	135	484		0.11	807	53	861
AM-AN	6	4.6	80	78.8	0.943	124	445		0.11	746	49	795
AN-AO	6	4.4	80	78.8	0.902	115	407		0.11	688	45	732
AO-AP	6	4.2	80	78.8	0.861	105	371		0.11	631	41	672
AP-AQ	6	4	80	78.8	0.820	96	336		0.11	577	37	614
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	65	67	0.681	84	232		0.11	502	25	528
AY-AZ	6	2.2	65	67	0.624	71	195		0.11	429	21	450
AZ-BA	6	2	65	67	0.567	60	161		0.11	361	18	378
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	50	51.3	0.677	116	229		3.62	696	830	1526
BD-BE	6	1.2	50	51.3	0.581	88	169		3.62	526	610	1136
BE-BF	6	1	50	51.3	0.484	63	117		3.62	379	424	803
BF-BG	6	0.8	40	40.4	0.624	135	195		3.16	811	615	1427
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	25	25.8	0.383	100	73	8	12	603	10878	11481
									TOTALS:	41346	25026	66372

Table B5: Pipe sizes selected based on limiting pressure loss of 250Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	300	315.9	2.552	149	3256		0.15	894	488	1383
B-C	6	100	250	265.8	1.802	95	1624	2	1.61	568	2615	3182
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	200	211.9	1.134	52	643		0.21	313	135	448
I-J	6	30	150	154.4	1.603	146	1284		0.2	877	257	1134
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	100	103.3	1.026	104	527		0.11	624	58	682
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	100	103.3	0.955	91	456		0.11	546	50	596
V-W	6	7.8	100	103.3	0.931	87	433		0.11	521	48	569
W-X	6	7.6	100	103.3	0.907	83	411		0.11	496	45	542
X-Y	6	7.4	100	103.3	0.883	79	390		0.11	473	43	516
Y-Z	6	7.2	100	103.3	0.859	75	369		0.11	449	41	490
Z-AB	6	7	100	103.3	0.835	71	349		0.11	427	38	465
AB-AC	6	6.8	100	103.3	0.812	67	329		0.11	404	36	441
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	80	78.8	1.272	216	808		0.11	1298	89	1387
AF-AG	6	6	80	78.8	1.231	204	757		0.11	1221	83	1304
AG-AH	6	5.8	80	78.8	1.189	191	707		0.11	1146	78	1224
AH-AI	6	5.6	80	78.8	1.148	179	659		0.11	1074	73	1147
AI-AJ	6	5.4	80	78.8	1.107	167	613		0.11	1004	67	1071
AJ-AK	6	5.2	80	78.8	1.066	156	568		0.11	936	63	999
AK-AL	6	5	80	78.8	1.025	145	526		0.11	871	58	928
AL-AM	6	4.8	80	78.8	0.984	135	484		0.11	807	53	861
AM-AN	6	4.6	80	78.8	0.943	124	445		0.11	746	49	795
AN-AO	6	4.4	80	78.8	0.902	115	407		0.11	688	45	732
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	65	67	0.681	84	232		0.11	502	25	528
AY-AZ	6	2.2	65	67	0.624	71	195		0.11	429	21	450
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	50	51.3	0.677	116	229		3.62	696	830	1526
BD-BE	6	1.2	50	51.3	0.581	88	169		3.62	526	610	1136
BE-BF	6	1	40	40.4	0.780	203	304		3.62	1216	1102	2318
BF-BG	6	0.8	40	40.4	0.624	135	195		3.16	811	615	1427
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	25	25.8	0.383	100	73	8	12	603	10878	11481
									TOTALS:	49570	28347	77916

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Table B6: Pipe sizes selected based on limiting pressure loss of 300Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	300	315.9	2.552	149	3256		0.15	894	488	1383
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	150	154.4	1.603	146	1284		0.2	877	257	1134
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	100	103.3	1.026	104	527		0.11	624	58	682
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	100	103.3	0.955	91	456		0.11	546	50	596
V-W	6	7.8	100	103.3	0.931	87	433		0.11	521	48	569
W-X	6	7.6	100	103.3	0.907	83	411		0.11	496	45	542
X-Y	6	7.4	100	103.3	0.883	79	390		0.11	473	43	516
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	80	78.8	1.272	216	808		0.11	1298	89	1387
AF-AG	6	6	80	78.8	1.231	204	757		0.11	1221	83	1304
AG-AH	6	5.8	80	78.8	1.189	191	707		0.11	1146	78	1224
AH-AI	6	5.6	80	78.8	1.148	179	659		0.11	1074	73	1147
AI-AJ	6	5.4	80	78.8	1.107	167	613		0.11	1004	67	1071
AJ-AK	6	5.2	80	78.8	1.066	156	568		0.11	936	63	999
AK-AL	6	5	80	78.8	1.025	145	526		0.11	871	58	928
AL-AM	6	4.8	80	78.8	0.984	135	484		0.11	807	53	861
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	65	67	0.681	84	232		0.11	502	25	528
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	50	51.3	0.677	116	229		3.62	696	830	1526
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	40	40.4	0.780	203	304		3.62	1216	1102	2318
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	25	25.8	0.383	100	73	8	12	603	10878	11481
									TOTALS:	60626	36701	97327

Table B7: Pipe sizes selected based on limiting pressure loss of 350Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	300	315.9	2.552	149	3256		0.15	894	488	1383
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	200	211.9	1.418	79	1005		0.21	475	211	686
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	150	154.4	1.603	146	1284		0.2	877	257	1134
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	100	103.3	1.026	104	527		0.11	624	58	682
S-T	6	8.4	100	103.3	1.002	100	502		0.11	597	55	653
T-U	6	8.2	100	103.3	0.979	95	479		0.11	571	53	624
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	80	78.8	1.272	216	808		0.11	1298	89	1387
AF-AG	6	6	80	78.8	1.231	204	757		0.11	1221	83	1304
AG-AH	6	5.8	80	78.8	1.189	191	707		0.11	1146	78	1224
AH-AI	6	5.6	80	78.8	1.148	179	659		0.11	1074	73	1147
AI-AJ	6	5.4	80	78.8	1.107	167	613		0.11	1004	67	1071
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	65	67	0.738	97	272		0.11	581	30	611
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	50	51.3	0.677	116	229		3.62	696	830	1526
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	40	40.4	0.780	203	304		3.62	1216	1102	2318
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	25	25.8	0.765	346	293		2.2	2079	644	2723
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	73791	42050	115840

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Table B8: Pipe sizes selected based on limiting pressure loss of 400Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	100	103.3	1.074	113	577		0.11	679	63	742
Q-R	6	8.8	100	103.3	1.050	109	551		0.11	651	61	712
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	80	78.8	1.272	216	808		0.11	1298	89	1387
AF-AG	6	6	80	78.8	1.231	204	757		0.11	1221	83	1304
AG-AH	6	5.8	80	78.8	1.189	191	707		0.11	1146	78	1224
AH-AI	6	5.6	80	78.8	1.148	179	659		0.11	1074	73	1147
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	65	67	0.794	111	315		0.11	666	35	700
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	40	40.4	0.780	203	304		3.62	1216	1102	2318
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	86066	47862	133929

Table B9: Pipe sizes selected based on limiting pressure loss of 450Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	100	103.3	1.146	128	656		0.11	765	72	838
N-O	6	9.4	100	103.3	1.122	123	629		0.11	736	69	805
O-P	6	9.2	100	103.3	1.098	118	603		0.11	707	66	774
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	80	78.8	1.272	216	808		0.11	1298	89	1387
AF-AG	6	6	80	78.8	1.231	204	757		0.11	1221	83	1304
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	65	67	0.851	126	362		0.11	755	40	795
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	50	51.3	0.774	148	300		3.62	887	1085	1972
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	25	25.8	0.765	346	293		2.2	2079	644	2723
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	97440	53419	150858

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Table B10: Pipe sizes selected based on limiting pressure loss of 500Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	200	211.9	1.702	112	1447		0.21	669	304	973
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	125	128.9	1.533	168	1175		0.15	1006	176	1182
K-L	6	10	100	103.3	1.193	138	712	2	1.51	826	1075	1901
L-M	6	9.8	100	103.3	1.170	133	684		0.11	795	75	871
M-N	6	9.6	80	78.8	1.969	492	1938		0.11	2950	213	3163
N-O	6	9.4	80	78.8	1.928	473	1858		0.11	2835	204	3039
O-P	6	9.2	80	78.8	1.887	454	1779		0.11	2722	196	2918
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	80	78.8	1.354	243	916		0.11	1459	101	1559
AD-AE	6	6.4	80	78.8	1.313	230	861		0.11	1377	95	1472
AE-AF	6	6.2	65	67	1.759	486	1546		0.11	2914	170	3084
AF-AG	6	6	65	67	1.702	457	1448		0.11	2740	159	2899
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	65	67	0.908	142	412		0.11	851	45	896
AU-AV	6	3	50	51.3	1.452	472	1053		4.14	2834	4361	7195
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	40	40.4	1.248	481	779		3.62	2886	2820	5706
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	109377	59595	168972

Table B11: Pipe sizes selected based on limiting pressure loss of 550Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	150	154.4	3.205	547	5135		0.21	3282	1078	4361
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	100	103.3	2.387	508	2848		0.15	3048	427	3475
K-L	6	10	80	78.8	2.051	531	2102	2	1.51	3187	3175	6362
L-M	6	9.8	80	78.8	2.010	511	2019		0.11	3068	222	3290
M-N	6	9.6	80	78.8	1.969	492	1938		0.11	2950	213	3163
N-O	6	9.4	80	78.8	1.928	473	1858		0.11	2835	204	3039
O-P	6	9.2	80	78.8	1.887	454	1779		0.11	2722	196	2918
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	80	78.8	1.395	257	972		0.11	1542	107	1649
AC-AD	6	6.6	65	67	1.872	546	1752		0.11	3279	193	3471
AD-AE	6	6.4	65	67	1.816	516	1648		0.11	3094	181	3275
AE-AF	6	6.2	65	67	1.759	486	1546		0.11	2914	170	3084
AF-AG	6	6	65	67	1.702	457	1448		0.11	2740	159	2899
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	65	67	0.965	159	465		0.11	951	51	1002
AT-AU	6	3.2	50	51.3	1.548	533	1199		4.14	3197	4962	8159
AU-AV	6	3	50	51.3	1.452	472	1053		4.14	2834	4361	7195
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	50	51.3	0.871	183	379		3.62	1101	1373	2473
BB-BC	6	1.6	40	40.4	1.248	481	779		3.62	2886	2820	5706
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	25	25.8	0.765	346	293		2.2	2079	644	2723
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	126123	68405	194528

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Table B12: Pipe sizes selected based on limiting pressure loss of 600Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	150	154.4	3.205	547	5135		0.21	3282	1078	4361
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	150	154.4	2.137	252	2282		0.21	1512	479	1991
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	100	103.3	2.387	508	2848		0.15	3048	427	3475
K-L	6	10	80	78.8	2.051	531	2102	2	1.51	3187	3175	6362
L-M	6	9.8	80	78.8	2.010	511	2019		0.11	3068	222	3290
M-N	6	9.6	80	78.8	1.969	492	1938		0.11	2950	213	3163
N-O	6	9.4	80	78.8	1.928	473	1858		0.11	2835	204	3039
O-P	6	9.2	80	78.8	1.887	454	1779		0.11	2722	196	2918
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	80	78.8	1.477	286	1090		0.11	1717	120	1836
Z-AB	6	7	80	78.8	1.436	271	1030		0.11	1628	113	1742
AB-AC	6	6.8	65	67	1.929	578	1860		0.11	3469	205	3673
AC-AD	6	6.6	65	67	1.872	546	1752		0.11	3279	193	3471
AD-AE	6	6.4	65	67	1.816	516	1648		0.11	3094	181	3275
AE-AF	6	6.2	65	67	1.759	486	1546		0.11	2914	170	3084
AF-AG	6	6	65	67	1.702	457	1448		0.11	2740	159	2899
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	50	51.3	1.645	597	1353		4.14	3582	5601	9184
AT-AU	6	3.2	50	51.3	1.548	533	1199		4.14	3197	4962	8159
AU-AV	6	3	50	51.3	1.452	472	1053		4.14	2834	4361	7195
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	40	40.4	1.404	599	986		3.62	3593	3569	7162
BB-BC	6	1.6	40	40.4	1.248	481	779		3.62	2886	2820	5706
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	40	40.4	0.936	283	438		3.62	1698	1586	3284
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	32	34.5	0.428	84	92		2.2	505	201	706
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	131599	75806	207405

Table B13: Pipe sizes selected based on limiting pressure loss of 650Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	150	154.4	3.205	547	5135		0.21	3282	1078	4361
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	125	128.9	3.066	626	4698		0.21	3754	987	4740
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	100	103.3	2.387	508	2848		0.15	3048	427	3475
K-L	6	10	80	78.8	2.051	531	2102	2	1.51	3187	3175	6362
L-M	6	9.8	80	78.8	2.010	511	2019		0.11	3068	222	3290
M-N	6	9.6	80	78.8	1.969	492	1938		0.11	2950	213	3163
N-O	6	9.4	80	78.8	1.928	473	1858		0.11	2835	204	3039
O-P	6	9.2	80	78.8	1.887	454	1779		0.11	2722	196	2918
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	80	78.8	1.518	301	1151		0.11	1807	127	1934
Y-Z	6	7.2	65	67	2.043	644	2085		0.11	3865	229	4094
Z-AB	6	7	65	67	1.986	611	1971		0.11	3664	217	3881
AB-AC	6	6.8	65	67	1.929	578	1860		0.11	3469	205	3673
AC-AD	6	6.6	65	67	1.872	546	1752		0.11	3279	193	3471
AD-AE	6	6.4	65	67	1.816	516	1648		0.11	3094	181	3275
AE-AF	6	6.2	65	67	1.759	486	1546		0.11	2914	170	3084
AF-AG	6	6	65	67	1.702	457	1448		0.11	2740	159	2899
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	65	67	1.021	176	521		0.11	1057	57	1114
AS-AT	6	3.4	50	51.3	1.645	597	1353		4.14	3582	5601	9184
AT-AU	6	3.2	50	51.3	1.548	533	1199		4.14	3197	4962	8159
AU-AV	6	3	50	51.3	1.452	472	1053		4.14	2834	4361	7195
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	40	40.4	1.404	599	986		3.62	3593	3569	7162
BB-BC	6	1.6	40	40.4	1.248	481	779		3.62	2886	2820	5706
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	32	34.5	1.284	618	824		3.62	3710	2983	6693
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	25	25.8	0.765	346	293		2.2	2079	644	2723
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	141612	78365	219977

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Table B14: Pipe sizes selected based on limiting pressure loss of 700Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Velocity (m/s)	Pressure loss per meter (Pa/m)	Velocity pressure (Pa)	No. Elbows	Fittings Zeta	Pipe losses (Pa)	Fitting losses (Pa)	Total losses (Pa)
A-B	6	200	250	265.8	3.605	356	6496		0.15	2136	974	3110
B-C	6	100	200	211.9	2.836	295	4021	2	1.61	1769	6473	8242
C-D	6	90	200	211.9	2.552	241	3257		0.21	1446	684	2130
D-E	6	80	200	211.9	2.269	193	2573		0.21	1155	540	1695
E-F	6	70	200	211.9	1.985	149	1970		0.21	896	414	1310
F-G	6	60	150	154.4	3.205	547	5135		0.21	3282	1078	4361
G-H	6	50	150	154.4	2.671	386	3566		0.21	2314	749	3063
H-I	6	40	125	128.9	3.066	626	4698		0.21	3754	987	4740
I-J	6	30	125	128.9	2.299	361	2643		0.2	2166	529	2694
J-K	6	20	100	103.3	2.387	508	2848		0.15	3048	427	3475
K-L	6	10	80	78.8	2.051	531	2102	2	1.51	3187	3175	6362
L-M	6	9.8	80	78.8	2.010	511	2019		0.11	3068	222	3290
M-N	6	9.6	80	78.8	1.969	492	1938		0.11	2950	213	3163
N-O	6	9.4	80	78.8	1.928	473	1858		0.11	2835	204	3039
O-P	6	9.2	80	78.8	1.887	454	1779		0.11	2722	196	2918
P-Q	6	9	80	78.8	1.846	435	1703		0.11	2612	187	2799
Q-R	6	8.8	80	78.8	1.805	417	1628		0.11	2503	179	2682
R-S	6	8.6	80	78.8	1.764	399	1555		0.11	2397	171	2568
S-T	6	8.4	80	78.8	1.723	382	1483		0.11	2293	163	2456
T-U	6	8.2	80	78.8	1.682	365	1414		0.11	2191	155	2347
U-V	6	8	80	78.8	1.641	349	1345		0.11	2092	148	2240
V-W	6	7.8	80	78.8	1.600	332	1279		0.11	1995	141	2135
W-X	6	7.6	80	78.8	1.559	317	1214		0.11	1900	134	2033
X-Y	6	7.4	65	67	2.099	678	2203		0.11	4071	242	4313
Y-Z	6	7.2	65	67	2.043	644	2085		0.11	3865	229	4094
Z-AB	6	7	65	67	1.986	611	1971		0.11	3664	217	3881
AB-AC	6	6.8	65	67	1.929	578	1860		0.11	3469	205	3673
AC-AD	6	6.6	65	67	1.872	546	1752		0.11	3279	193	3471
AD-AE	6	6.4	65	67	1.816	516	1648		0.11	3094	181	3275
AE-AF	6	6.2	65	67	1.759	486	1546		0.11	2914	170	3084
AF-AG	6	6	65	67	1.702	457	1448		0.11	2740	159	2899
AG-AH	6	5.8	65	67	1.645	428	1353		0.11	2571	149	2719
AH-AI	6	5.6	65	67	1.589	401	1261		0.11	2407	139	2545
AI-AJ	6	5.4	65	67	1.532	375	1173		0.11	2248	129	2377
AJ-AK	6	5.2	65	67	1.475	349	1088		0.11	2094	120	2214
AK-AL	6	5	65	67	1.418	324	1006		0.11	1946	111	2057
AL-AM	6	4.8	65	67	1.362	301	927		0.11	1803	102	1905
AM-AN	6	4.6	65	67	1.305	278	851		0.11	1666	94	1759
AN-AO	6	4.4	65	67	1.248	256	779		0.11	1533	86	1619
AO-AP	6	4.2	65	67	1.191	234	710		0.11	1406	78	1484
AP-AQ	6	4	65	67	1.135	214	644		0.11	1285	71	1355
AQ-AR	6	3.8	65	67	1.078	195	581		0.11	1168	64	1232
AR-AS	6	3.6	50	51.3	1.742	665	1517		4.14	3988	6280	10268
AS-AT	6	3.4	50	51.3	1.645	597	1353		4.14	3582	5601	9184
AT-AU	6	3.2	50	51.3	1.548	533	1199		4.14	3197	4962	8159
AU-AV	6	3	50	51.3	1.452	472	1053		4.14	2834	4361	7195
AV-AW	6	2.8	50	51.3	1.355	415	918		4.14	2491	3799	6290
AW-AX	6	2.6	50	51.3	1.258	362	791		4.14	2170	3276	5446
AX-AY	6	2.4	50	51.3	1.161	312	674		4.14	1871	2791	4662
AY-AZ	6	2.2	50	51.3	1.065	265	566		4.14	1593	2345	3938
AZ-BA	6	2	50	51.3	0.968	223	468		4.14	1336	1938	3274
BA-BB	6	1.8	40	40.4	1.404	599	986		3.62	3593	3569	7162
BB-BC	6	1.6	40	40.4	1.248	481	779		3.62	2886	2820	5706
BC-BD	6	1.4	40	40.4	1.092	376	596		3.62	2254	2159	4413
BD-BE	6	1.2	32	34.5	1.284	618	824		3.62	3710	2983	6693
BE-BF	6	1	32	34.5	1.070	441	572		3.62	2649	2071	4720
BF-BG	6	0.8	32	34.5	0.856	293	366		3.16	1759	1157	2916
BG-BH	6	0.6	32	34.5	0.642	174	206		2.77	1043	571	1614
BH-BI	6	0.4	25	25.8	0.765	346	293		2.2	2079	644	2723
BI-BJ	6	0.2	20	20.5	0.606	306	184	8	13.6	1837	12497	14334
									TOTALS:	146807	84704	231510

Appendix: C
Embodied Energy Calculation Results

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Table C1: Embodied energy for pipe sizes selected based on limiting pressure loss of 50Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	400	398.4	0.030	236.7	8142	2262
B-C	6	100	300	315.9	0.024	188.2	6473	1798
C-D	6	90	300	315.9	0.024	188.2	6473	1798
D-E	6	80	300	315.9	0.024	188.2	6473	1798
E-F	6	70	250	265.8	0.018	142.6	4906	1363
F-G	6	60	250	265.8	0.018	142.6	4906	1363
G-H	6	50	250	265.8	0.018	142.6	4906	1363
H-I	6	40	250	265.8	0.018	142.6	4906	1363
I-J	6	30	200	211.9	0.015	114.1	3924	1090
J-K	6	20	200	211.9	0.015	114.1	3924	1090
K-L	6	10	125	128.9	0.014	106.6	3668	1019
L-M	6	9.8	125	128.9	0.014	106.6	3668	1019
M-N	6	9.6	125	128.9	0.014	106.6	3668	1019
N-O	6	9.4	125	128.9	0.014	106.6	3668	1019
O-P	6	9.2	125	128.9	0.014	106.6	3668	1019
P-Q	6	9	125	128.9	0.014	106.6	3668	1019
Q-R	6	8.8	125	128.9	0.014	106.6	3668	1019
R-S	6	8.6	125	128.9	0.014	106.6	3668	1019
S-T	6	8.4	125	128.9	0.014	106.6	3668	1019
T-U	6	8.2	125	128.9	0.014	106.6	3668	1019
U-V	6	8	125	128.9	0.014	106.6	3668	1019
V-W	6	7.8	125	128.9	0.014	106.6	3668	1019
W-X	6	7.6	125	128.9	0.014	106.6	3668	1019
X-Y	6	7.4	125	128.9	0.014	106.6	3668	1019
Y-Z	6	7.2	125	128.9	0.014	106.6	3668	1019
Z-AB	6	7	125	128.9	0.014	106.6	3668	1019
AB-AC	6	6.8	125	128.9	0.014	106.6	3668	1019
AC-AD	6	6.6	125	128.9	0.014	106.6	3668	1019
AD-AE	6	6.4	125	128.9	0.014	106.6	3668	1019
AE-AF	6	6.2	125	128.9	0.014	106.6	3668	1019
AF-AG	6	6	125	128.9	0.014	106.6	3668	1019
AG-AH	6	5.8	100	103.3	0.011	88.0	3027	841
AH-AI	6	5.6	100	103.3	0.011	88.0	3027	841
AI-AJ	6	5.4	100	103.3	0.011	88.0	3027	841
AJ-AK	6	5.2	100	103.3	0.011	88.0	3027	841
AK-AL	6	5	100	103.3	0.011	88.0	3027	841
AL-AM	6	4.8	100	103.3	0.011	88.0	3027	841
AM-AN	6	4.6	100	103.3	0.011	88.0	3027	841
AN-AO	6	4.4	100	103.3	0.011	88.0	3027	841
AO-AP	6	4.2	100	103.3	0.011	88.0	3027	841
AP-AQ	6	4	100	103.3	0.011	88.0	3027	841
AQ-AR	6	3.8	100	103.3	0.011	88.0	3027	841
AR-AS	6	3.6	100	103.3	0.011	88.0	3027	841
AS-AT	6	3.4	100	103.3	0.011	88.0	3027	841
AT-AU	6	3.2	100	103.3	0.011	88.0	3027	841
AU-AV	6	3	100	103.3	0.011	88.0	3027	841
AV-AW	6	2.8	80	78.8	0.008	62.3	2142	595
AW-AX	6	2.6	80	78.8	0.008	62.3	2142	595
AX-AY	6	2.4	80	78.8	0.008	62.3	2142	595
AY-AZ	6	2.2	80	78.8	0.008	62.3	2142	595
AZ-BA	6	2	80	78.8	0.008	62.3	2142	595
BA-BB	6	1.8	65	67	0.006	47.9	1647	457
BB-BC	6	1.6	65	67	0.006	47.9	1647	457
BC-BD	6	1.4	65	67	0.006	47.9	1647	457
BD-BE	6	1.2	65	67	0.006	47.9	1647	457
BE-BF	6	1	65	67	0.006	47.9	1647	457
BF-BG	6	0.8	50	51.3	0.005	36.9	1270	353
BG-BH	6	0.6	50	51.3	0.005	36.9	1270	353
BH-BI	6	0.4	40	40.4	0.003	25.8	886	246
BI-BJ	6	0.2	32	34.5	0.003	22.3	768	213
					0.748	5832	200611	55725

Table C2: Embodied energy for pipe sizes selected based on limiting pressure loss of 100Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	350	347.6	0.027	206.8	7114	1976
B-C	6	100	250	265.8	0.018	142.6	4906	1363
C-D	6	90	250	265.8	0.018	142.6	4906	1363
D-E	6	80	250	265.8	0.018	142.6	4906	1363
E-F	6	70	250	265.8	0.018	142.6	4906	1363
F-G	6	60	250	265.8	0.018	142.6	4906	1363
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	200	211.9	0.015	114.1	3924	1090
I-J	6	30	200	211.9	0.015	114.1	3924	1090
J-K	6	20	150	154.4	0.016	125.7	4323	1201
K-L	6	10	125	128.9	0.014	106.6	3668	1019
L-M	6	9.8	125	128.9	0.014	106.6	3668	1019
M-N	6	9.6	125	128.9	0.014	106.6	3668	1019
N-O	6	9.4	125	128.9	0.014	106.6	3668	1019
O-P	6	9.2	125	128.9	0.014	106.6	3668	1019
P-Q	6	9	125	128.9	0.014	106.6	3668	1019
Q-R	6	8.8	125	128.9	0.014	106.6	3668	1019
R-S	6	8.6	125	128.9	0.014	106.6	3668	1019
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	100	103.3	0.011	88.0	3027	841
V-W	6	7.8	100	103.3	0.011	88.0	3027	841
W-X	6	7.6	100	103.3	0.011	88.0	3027	841
X-Y	6	7.4	100	103.3	0.011	88.0	3027	841
Y-Z	6	7.2	100	103.3	0.011	88.0	3027	841
Z-AB	6	7	100	103.3	0.011	88.0	3027	841
AB-AC	6	6.8	100	103.3	0.011	88.0	3027	841
AC-AD	6	6.6	100	103.3	0.011	88.0	3027	841
AD-AE	6	6.4	100	103.3	0.011	88.0	3027	841
AE-AF	6	6.2	100	103.3	0.011	88.0	3027	841
AF-AG	6	6	100	103.3	0.011	88.0	3027	841
AG-AH	6	5.8	100	103.3	0.011	88.0	3027	841
AH-AI	6	5.6	100	103.3	0.011	88.0	3027	841
AI-AJ	6	5.4	100	103.3	0.011	88.0	3027	841
AJ-AK	6	5.2	100	103.3	0.011	88.0	3027	841
AK-AL	6	5	100	103.3	0.011	88.0	3027	841
AL-AM	6	4.8	100	103.3	0.011	88.0	3027	841
AM-AN	6	4.6	100	103.3	0.011	88.0	3027	841
AN-AO	6	4.4	100	103.3	0.011	88.0	3027	841
AO-AP	6	4.2	100	103.3	0.011	88.0	3027	841
AP-AQ	6	4	80	78.8	0.008	62.3	2142	595
AQ-AR	6	3.8	80	78.8	0.008	62.3	2142	595
AR-AS	6	3.6	80	78.8	0.008	62.3	2142	595
AS-AT	6	3.4	80	78.8	0.008	62.3	2142	595
AT-AU	6	3.2	80	78.8	0.008	62.3	2142	595
AU-AV	6	3	80	78.8	0.008	62.3	2142	595
AV-AW	6	2.8	80	78.8	0.008	62.3	2142	595
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	65	67	0.006	47.9	1647	457
AY-AZ	6	2.2	65	67	0.006	47.9	1647	457
AZ-BA	6	2	65	67	0.006	47.9	1647	457
BA-BB	6	1.8	65	67	0.006	47.9	1647	457
BB-BC	6	1.6	65	67	0.006	47.9	1647	457
BC-BD	6	1.4	65	67	0.006	47.9	1647	457
BD-BE	6	1.2	50	51.3	0.005	36.9	1270	353
BE-BF	6	1	50	51.3	0.005	36.9	1270	353
BF-BG	6	0.8	50	51.3	0.005	36.9	1270	353
BG-BH	6	0.6	40	40.4	0.003	25.8	886	246
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	25	25.8	0.002	17.3	594	165
					0.657	5124	176259	48961

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Table C3: Embodied energy for pipe sizes selected based on limiting pressure loss of 150Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	300	315.9	0.024	188.2	6473	1798
B-C	6	100	250	265.8	0.018	142.6	4906	1363
C-D	6	90	250	265.8	0.018	142.6	4906	1363
D-E	6	80	250	265.8	0.018	142.6	4906	1363
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	200	211.9	0.015	114.1	3924	1090
I-J	6	30	150	154.4	0.016	125.7	4323	1201
J-K	6	20	150	154.4	0.016	125.7	4323	1201
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	100	103.3	0.011	88.0	3027	841
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	100	103.3	0.011	88.0	3027	841
V-W	6	7.8	100	103.3	0.011	88.0	3027	841
W-X	6	7.6	100	103.3	0.011	88.0	3027	841
X-Y	6	7.4	100	103.3	0.011	88.0	3027	841
Y-Z	6	7.2	100	103.3	0.011	88.0	3027	841
Z-AB	6	7	100	103.3	0.011	88.0	3027	841
AB-AC	6	6.8	100	103.3	0.011	88.0	3027	841
AC-AD	6	6.6	100	103.3	0.011	88.0	3027	841
AD-AE	6	6.4	100	103.3	0.011	88.0	3027	841
AE-AF	6	6.2	100	103.3	0.011	88.0	3027	841
AF-AG	6	6	100	103.3	0.011	88.0	3027	841
AG-AH	6	5.8	100	103.3	0.011	88.0	3027	841
AH-AI	6	5.6	100	103.3	0.011	88.0	3027	841
AI-AJ	6	5.4	100	103.3	0.011	88.0	3027	841
AJ-AK	6	5.2	100	103.3	0.011	88.0	3027	841
AK-AL	6	5	80	78.8	0.008	62.3	2142	595
AL-AM	6	4.8	80	78.8	0.008	62.3	2142	595
AM-AN	6	4.6	80	78.8	0.008	62.3	2142	595
AN-AO	6	4.4	80	78.8	0.008	62.3	2142	595
AO-AP	6	4.2	80	78.8	0.008	62.3	2142	595
AP-AQ	6	4	80	78.8	0.008	62.3	2142	595
AQ-AR	6	3.8	80	78.8	0.008	62.3	2142	595
AR-AS	6	3.6	80	78.8	0.008	62.3	2142	595
AS-AT	6	3.4	80	78.8	0.008	62.3	2142	595
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	65	67	0.006	47.9	1647	457
AY-AZ	6	2.2	65	67	0.006	47.9	1647	457
AZ-BA	6	2	65	67	0.006	47.9	1647	457
BA-BB	6	1.8	65	67	0.006	47.9	1647	457
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	50	51.3	0.005	36.9	1270	353
BD-BE	6	1.2	50	51.3	0.005	36.9	1270	353
BE-BF	6	1	50	51.3	0.005	36.9	1270	353
BF-BG	6	0.8	40	40.4	0.003	25.8	886	246
BG-BH	6	0.6	40	40.4	0.003	25.8	886	246
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	25	25.8	0.002	17.3	594	165
					0.603	4706	161874	44965

Table C4: Embodied energy for pipe sizes selected based on limiting pressure loss of 200Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	300	315.9	0.024	188.2	6473	1798
B-C	6	100	250	265.8	0.018	142.6	4906	1363
C-D	6	90	250	265.8	0.018	142.6	4906	1363
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	200	211.9	0.015	114.1	3924	1090
I-J	6	30	150	154.4	0.016	125.7	4323	1201
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	100	103.3	0.011	88.0	3027	841
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	100	103.3	0.011	88.0	3027	841
V-W	6	7.8	100	103.3	0.011	88.0	3027	841
W-X	6	7.6	100	103.3	0.011	88.0	3027	841
X-Y	6	7.4	100	103.3	0.011	88.0	3027	841
Y-Z	6	7.2	100	103.3	0.011	88.0	3027	841
Z-AB	6	7	100	103.3	0.011	88.0	3027	841
AB-AC	6	6.8	100	103.3	0.011	88.0	3027	841
AC-AD	6	6.6	100	103.3	0.011	88.0	3027	841
AD-AE	6	6.4	100	103.3	0.011	88.0	3027	841
AE-AF	6	6.2	100	103.3	0.011	88.0	3027	841
AF-AG	6	6	100	103.3	0.011	88.0	3027	841
AG-AH	6	5.8	80	78.8	0.008	62.3	2142	595
AH-AI	6	5.6	80	78.8	0.008	62.3	2142	595
AI-AJ	6	5.4	80	78.8	0.008	62.3	2142	595
AJ-AK	6	5.2	80	78.8	0.008	62.3	2142	595
AK-AL	6	5	80	78.8	0.008	62.3	2142	595
AL-AM	6	4.8	80	78.8	0.008	62.3	2142	595
AM-AN	6	4.6	80	78.8	0.008	62.3	2142	595
AN-AO	6	4.4	80	78.8	0.008	62.3	2142	595
AO-AP	6	4.2	80	78.8	0.008	62.3	2142	595
AP-AQ	6	4	80	78.8	0.008	62.3	2142	595
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	65	67	0.006	47.9	1647	457
AY-AZ	6	2.2	65	67	0.006	47.9	1647	457
AZ-BA	6	2	65	67	0.006	47.9	1647	457
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	50	51.3	0.005	36.9	1270	353
BD-BE	6	1.2	50	51.3	0.005	36.9	1270	353
BE-BF	6	1	50	51.3	0.005	36.9	1270	353
BF-BG	6	0.8	40	40.4	0.003	25.8	886	246
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	25	25.8	0.002	17.3	594	165
					0.577	4498	154718	42977

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Table C5: Embodied energy for pipe sizes selected based on limiting pressure loss of 250Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	300	315.9	0.024	188.2	6473	1798
B-C	6	100	250	265.8	0.018	142.6	4906	1363
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	200	211.9	0.015	114.1	3924	1090
I-J	6	30	150	154.4	0.016	125.7	4323	1201
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	100	103.3	0.011	88.0	3027	841
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	100	103.3	0.011	88.0	3027	841
V-W	6	7.8	100	103.3	0.011	88.0	3027	841
W-X	6	7.6	100	103.3	0.011	88.0	3027	841
X-Y	6	7.4	100	103.3	0.011	88.0	3027	841
Y-Z	6	7.2	100	103.3	0.011	88.0	3027	841
Z-AB	6	7	100	103.3	0.011	88.0	3027	841
AB-AC	6	6.8	100	103.3	0.011	88.0	3027	841
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	80	78.8	0.008	62.3	2142	595
AF-AG	6	6	80	78.8	0.008	62.3	2142	595
AG-AH	6	5.8	80	78.8	0.008	62.3	2142	595
AH-AI	6	5.6	80	78.8	0.008	62.3	2142	595
AI-AJ	6	5.4	80	78.8	0.008	62.3	2142	595
AJ-AK	6	5.2	80	78.8	0.008	62.3	2142	595
AK-AL	6	5	80	78.8	0.008	62.3	2142	595
AL-AM	6	4.8	80	78.8	0.008	62.3	2142	595
AM-AN	6	4.6	80	78.8	0.008	62.3	2142	595
AN-AO	6	4.4	80	78.8	0.008	62.3	2142	595
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	65	67	0.006	47.9	1647	457
AY-AZ	6	2.2	65	67	0.006	47.9	1647	457
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	50	51.3	0.005	36.9	1270	353
BD-BE	6	1.2	50	51.3	0.005	36.9	1270	353
BE-BF	6	1	40	40.4	0.003	25.8	886	246
BF-BG	6	0.8	40	40.4	0.003	25.8	886	246
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	25	25.8	0.002	17.3	594	165
					0.553	4315	148445	41235

Table C6: Embodied energy for pipe sizes selected based on limiting pressure loss of 300Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	300	315.9	0.024	188.2	6473	1798
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	150	154.4	0.016	125.7	4323	1201
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	100	103.3	0.011	88.0	3027	841
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	100	103.3	0.011	88.0	3027	841
V-W	6	7.8	100	103.3	0.011	88.0	3027	841
W-X	6	7.6	100	103.3	0.011	88.0	3027	841
X-Y	6	7.4	100	103.3	0.011	88.0	3027	841
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	80	78.8	0.008	62.3	2142	595
AF-AG	6	6	80	78.8	0.008	62.3	2142	595
AG-AH	6	5.8	80	78.8	0.008	62.3	2142	595
AH-AI	6	5.6	80	78.8	0.008	62.3	2142	595
AI-AJ	6	5.4	80	78.8	0.008	62.3	2142	595
AJ-AK	6	5.2	80	78.8	0.008	62.3	2142	595
AK-AL	6	5	80	78.8	0.008	62.3	2142	595
AL-AM	6	4.8	80	78.8	0.008	62.3	2142	595
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	65	67	0.006	47.9	1647	457
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	50	51.3	0.005	36.9	1270	353
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	40	40.4	0.003	25.8	886	246
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	25	25.8	0.002	17.3	594	165
					0.534	4167	143339	39816

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Table C7: Embodied energy for pipe sizes selected based on limiting pressure loss of 350Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	300	315.9	0.024	188.2	6473	1798
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	200	211.9	0.015	114.1	3924	1090
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	150	154.4	0.016	125.7	4323	1201
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	100	103.3	0.011	88.0	3027	841
S-T	6	8.4	100	103.3	0.011	88.0	3027	841
T-U	6	8.2	100	103.3	0.011	88.0	3027	841
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	80	78.8	0.008	62.3	2142	595
AF-AG	6	6	80	78.8	0.008	62.3	2142	595
AG-AH	6	5.8	80	78.8	0.008	62.3	2142	595
AH-AI	6	5.6	80	78.8	0.008	62.3	2142	595
AI-AJ	6	5.4	80	78.8	0.008	62.3	2142	595
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	65	67	0.006	47.9	1647	457
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	50	51.3	0.005	36.9	1270	353
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	40	40.4	0.003	25.8	886	246
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	25	25.8	0.002	17.3	594	165
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.513	3999	137552	38209

Table C8: Embodied energy for pipe sizes selected based on limiting pressure loss of 400Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	100	103.3	0.011	88.0	3027	841
Q-R	6	8.8	100	103.3	0.011	88.0	3027	841
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	80	78.8	0.008	62.3	2142	595
AF-AG	6	6	80	78.8	0.008	62.3	2142	595
AG-AH	6	5.8	80	78.8	0.008	62.3	2142	595
AH-AI	6	5.6	80	78.8	0.008	62.3	2142	595
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	65	67	0.006	47.9	1647	457
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	40	40.4	0.003	25.8	886	246
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.492	3837	131992	36665

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Table C9: Embodied energy for pipe sizes selected based on limiting pressure loss of 450Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	100	103.3	0.011	88.0	3027	841
N-O	6	9.4	100	103.3	0.011	88.0	3027	841
O-P	6	9.2	100	103.3	0.011	88.0	3027	841
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	80	78.8	0.008	62.3	2142	595
AF-AG	6	6	80	78.8	0.008	62.3	2142	595
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	65	67	0.006	47.9	1647	457
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	50	51.3	0.005	36.9	1270	353
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	25	25.8	0.002	17.3	594	165
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.479	3737	128564	35712

Table C10: Embodied energy for pipe sizes selected based on limiting pressure loss of 500Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	200	211.9	0.015	114.1	3924	1090
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	125	128.9	0.014	106.6	3668	1019
K-L	6	10	100	103.3	0.011	88.0	3027	841
L-M	6	9.8	100	103.3	0.011	88.0	3027	841
M-N	6	9.6	80	78.8	0.008	62.3	2142	595
N-O	6	9.4	80	78.8	0.008	62.3	2142	595
O-P	6	9.2	80	78.8	0.008	62.3	2142	595
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	80	78.8	0.008	62.3	2142	595
AD-AE	6	6.4	80	78.8	0.008	62.3	2142	595
AE-AF	6	6.2	65	67	0.006	47.9	1647	457
AF-AG	6	6	65	67	0.006	47.9	1647	457
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	65	67	0.006	47.9	1647	457
AU-AV	6	3	50	51.3	0.005	36.9	1270	353
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	40	40.4	0.003	25.8	886	246
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.463	3614	124331	34537

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Table C11: Embodied energy for pipe sizes selected based on limiting pressure loss of 550Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	150	154.4	0.016	125.7	4323	1201
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	100	103.3	0.011	88.0	3027	841
K-L	6	10	80	78.8	0.008	62.3	2142	595
L-M	6	9.8	80	78.8	0.008	62.3	2142	595
M-N	6	9.6	80	78.8	0.008	62.3	2142	595
N-O	6	9.4	80	78.8	0.008	62.3	2142	595
O-P	6	9.2	80	78.8	0.008	62.3	2142	595
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	80	78.8	0.008	62.3	2142	595
AC-AD	6	6.6	65	67	0.006	47.9	1647	457
AD-AE	6	6.4	65	67	0.006	47.9	1647	457
AE-AF	6	6.2	65	67	0.006	47.9	1647	457
AF-AG	6	6	65	67	0.006	47.9	1647	457
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	65	67	0.006	47.9	1647	457
AT-AU	6	3.2	50	51.3	0.005	36.9	1270	353
AU-AV	6	3	50	51.3	0.005	36.9	1270	353
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	50	51.3	0.005	36.9	1270	353
BB-BC	6	1.6	40	40.4	0.003	25.8	886	246
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	25	25.8	0.002	17.3	594	165
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.450	3511	120778	33549

Table C12: Embodied energy for pipe sizes selected based on limiting pressure loss of 600Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	150	154.4	0.016	125.7	4323	1201
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	150	154.4	0.016	125.7	4323	1201
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	100	103.3	0.011	88.0	3027	841
K-L	6	10	80	78.8	0.008	62.3	2142	595
L-M	6	9.8	80	78.8	0.008	62.3	2142	595
M-N	6	9.6	80	78.8	0.008	62.3	2142	595
N-O	6	9.4	80	78.8	0.008	62.3	2142	595
O-P	6	9.2	80	78.8	0.008	62.3	2142	595
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	80	78.8	0.008	62.3	2142	595
Z-AB	6	7	80	78.8	0.008	62.3	2142	595
AB-AC	6	6.8	65	67	0.006	47.9	1647	457
AC-AD	6	6.6	65	67	0.006	47.9	1647	457
AD-AE	6	6.4	65	67	0.006	47.9	1647	457
AE-AF	6	6.2	65	67	0.006	47.9	1647	457
AF-AG	6	6	65	67	0.006	47.9	1647	457
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	50	51.3	0.005	36.9	1270	353
AT-AU	6	3.2	50	51.3	0.005	36.9	1270	353
AU-AV	6	3	50	51.3	0.005	36.9	1270	353
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	40	40.4	0.003	25.8	886	246
BB-BC	6	1.6	40	40.4	0.003	25.8	886	246
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	40	40.4	0.003	25.8	886	246
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	32	34.5	0.003	22.3	768	213
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.446	3480	119696	33249

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Table C13: Embodied energy for pipe sizes selected based on limiting pressure loss of 650Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	150	154.4	0.016	125.7	4323	1201
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	125	128.9	0.014	106.6	3668	1019
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	100	103.3	0.011	88.0	3027	841
K-L	6	10	80	78.8	0.008	62.3	2142	595
L-M	6	9.8	80	78.8	0.008	62.3	2142	595
M-N	6	9.6	80	78.8	0.008	62.3	2142	595
N-O	6	9.4	80	78.8	0.008	62.3	2142	595
O-P	6	9.2	80	78.8	0.008	62.3	2142	595
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	80	78.8	0.008	62.3	2142	595
Y-Z	6	7.2	65	67	0.006	47.9	1647	457
Z-AB	6	7	65	67	0.006	47.9	1647	457
AB-AC	6	6.8	65	67	0.006	47.9	1647	457
AC-AD	6	6.6	65	67	0.006	47.9	1647	457
AD-AE	6	6.4	65	67	0.006	47.9	1647	457
AE-AF	6	6.2	65	67	0.006	47.9	1647	457
AF-AG	6	6	65	67	0.006	47.9	1647	457
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	65	67	0.006	47.9	1647	457
AS-AT	6	3.4	50	51.3	0.005	36.9	1270	353
AT-AU	6	3.2	50	51.3	0.005	36.9	1270	353
AU-AV	6	3	50	51.3	0.005	36.9	1270	353
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	40	40.4	0.003	25.8	886	246
BB-BC	6	1.6	40	40.4	0.003	25.8	886	246
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	32	34.5	0.003	22.3	768	213
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	25	25.8	0.002	17.3	594	165
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.439	3423	117759	32711

Table C14: Embodied energy for pipe sizes selected based on limiting pressure loss of 700Pa/m

Section	Length (m)	Mass flow (kg/s)	Nominal diameter (mm)	Internal diameter (mm)	Volume of steel (m3)	Mass of steel (kg)	Embodied energy (MJ)	Embodied energy (kWh)
A-B	6	200	250	265.8	0.018	142.6	4906	1363
B-C	6	100	200	211.9	0.015	114.1	3924	1090
C-D	6	90	200	211.9	0.015	114.1	3924	1090
D-E	6	80	200	211.9	0.015	114.1	3924	1090
E-F	6	70	200	211.9	0.015	114.1	3924	1090
F-G	6	60	150	154.4	0.016	125.7	4323	1201
G-H	6	50	150	154.4	0.016	125.7	4323	1201
H-I	6	40	125	128.9	0.014	106.6	3668	1019
I-J	6	30	125	128.9	0.014	106.6	3668	1019
J-K	6	20	100	103.3	0.011	88.0	3027	841
K-L	6	10	80	78.8	0.008	62.3	2142	595
L-M	6	9.8	80	78.8	0.008	62.3	2142	595
M-N	6	9.6	80	78.8	0.008	62.3	2142	595
N-O	6	9.4	80	78.8	0.008	62.3	2142	595
O-P	6	9.2	80	78.8	0.008	62.3	2142	595
P-Q	6	9	80	78.8	0.008	62.3	2142	595
Q-R	6	8.8	80	78.8	0.008	62.3	2142	595
R-S	6	8.6	80	78.8	0.008	62.3	2142	595
S-T	6	8.4	80	78.8	0.008	62.3	2142	595
T-U	6	8.2	80	78.8	0.008	62.3	2142	595
U-V	6	8	80	78.8	0.008	62.3	2142	595
V-W	6	7.8	80	78.8	0.008	62.3	2142	595
W-X	6	7.6	80	78.8	0.008	62.3	2142	595
X-Y	6	7.4	65	67	0.006	47.9	1647	457
Y-Z	6	7.2	65	67	0.006	47.9	1647	457
Z-AB	6	7	65	67	0.006	47.9	1647	457
AB-AC	6	6.8	65	67	0.006	47.9	1647	457
AC-AD	6	6.6	65	67	0.006	47.9	1647	457
AD-AE	6	6.4	65	67	0.006	47.9	1647	457
AE-AF	6	6.2	65	67	0.006	47.9	1647	457
AF-AG	6	6	65	67	0.006	47.9	1647	457
AG-AH	6	5.8	65	67	0.006	47.9	1647	457
AH-AI	6	5.6	65	67	0.006	47.9	1647	457
AI-AJ	6	5.4	65	67	0.006	47.9	1647	457
AJ-AK	6	5.2	65	67	0.006	47.9	1647	457
AK-AL	6	5	65	67	0.006	47.9	1647	457
AL-AM	6	4.8	65	67	0.006	47.9	1647	457
AM-AN	6	4.6	65	67	0.006	47.9	1647	457
AN-AO	6	4.4	65	67	0.006	47.9	1647	457
AO-AP	6	4.2	65	67	0.006	47.9	1647	457
AP-AQ	6	4	65	67	0.006	47.9	1647	457
AQ-AR	6	3.8	65	67	0.006	47.9	1647	457
AR-AS	6	3.6	50	51.3	0.005	36.9	1270	353
AS-AT	6	3.4	50	51.3	0.005	36.9	1270	353
AT-AU	6	3.2	50	51.3	0.005	36.9	1270	353
AU-AV	6	3	50	51.3	0.005	36.9	1270	353
AV-AW	6	2.8	50	51.3	0.005	36.9	1270	353
AW-AX	6	2.6	50	51.3	0.005	36.9	1270	353
AX-AY	6	2.4	50	51.3	0.005	36.9	1270	353
AY-AZ	6	2.2	50	51.3	0.005	36.9	1270	353
AZ-BA	6	2	50	51.3	0.005	36.9	1270	353
BA-BB	6	1.8	40	40.4	0.003	25.8	886	246
BB-BC	6	1.6	40	40.4	0.003	25.8	886	246
BC-BD	6	1.4	40	40.4	0.003	25.8	886	246
BD-BE	6	1.2	32	34.5	0.003	22.3	768	213
BE-BF	6	1	32	34.5	0.003	22.3	768	213
BF-BG	6	0.8	32	34.5	0.003	22.3	768	213
BG-BH	6	0.6	32	34.5	0.003	22.3	768	213
BH-BI	6	0.4	25	25.8	0.002	17.3	594	165
BI-BJ	6	0.2	20	20.5	0.001	11.2	384	107
					0.436	3398	116888	32469

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