STUDY OF A DISTRICT HEATING SYSTEM IN AKUREYRI, ICELAND

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ABSTRACT

Design of geothermal district heating system is based on theoretical analysis and practical calculations.

The actual district heating system in the city of Akureyri was used as an example to analyze and calculate a geothermal district heating system and to present analysis and calculation results in this report.

This analysis shows too high pressure loss in some pipes. The reason for this is not wrong design of the system, but that here the Icelandic Standard for building heat loss calculations was used for estimating the pipe flow rates. These pipe flow rates are considerably higher than what is experienced in the real situation.

Studies are made on the effect of radiator size on the water consumption. They indicate that total yearly water consumption can be reduced by increasing the radiator area. Two increases of radiator area were calculated, 16% and 42%. They gave 4% and 17% water consumption reduction respectively.

The most important target for this report is to get a understanding of the main factors involved in the design process of geothermal district heating system.

TABLE OF CONTENTS

ABSTRACT..iii

TABLE OF CONTENTS...v

LIST OF FIGURES...vii

LIST OF TABLES...viii

LIST OF SYMBOLS..ix

1. INTRODUCTION..1
   1.1 Scope of the Work.....................................1
   1.2 Purpose of the Study..................................2

2. DESCRIPTION OF THE SELECTED SYSTEM........................4
   2.1 Brief Introduction....................................4
   2.2 Geothermal Resources of the Selected System...........4
   2.3 Description of the Geothermal Engineering.............5

3. WEATHER ANALYSIS:...9
   3.1 Cold Wave of the Selected System......................9
   3.2 Outside Temperature Duration Curve....................9
   3.3 System Design Temperature.............................9

4. DESCRIPTION OF LOCAL BUILDINGS...........................11
   4.1 Heat Loss Calculation................................11
   4.2 Heat Capacity Calculation............................16
   4.3 Summary..19

5. STUDY OF THE DISTRIBUTION SYSTEM.........................21
   5.1 Calculation of Friction Factor in the Pipes..........21
   5.2 Pipeline System Design...............................24

6. STUDY OF THE SUPPLY SYSTEM....................................35
   6.1 Water Supply Situation...................................35
   6.2 Possibilities of Reducing Water Consumption.........38
   6.3 Possibilities of Increasing Water Supply............40

7. DISCUSSION AND CONCLUSION.....................................41

ACKNOWLEDGEMENTS...42

REFERENCES...43

APPENDICES...44

LIST OF FIGURES

Figure 2-1 Akureyri City and Geothermal Fields.............47

Figure 2-2 Selected System of a Part of Gerdahverfi II, Akureyri..48

Figure 2-3 Akureyri Central Heating System.................49

Figure 3-1 Ambient Temperature During a Cold Spell.........50

Figure 3-2 Outside Temperature Duration Curve of Akureyri, Iceland (from 1970 to 1987).....................51

Figure 3-3 Ambient Temperature Below Tg and Inside Temperature During a Cold Spell.................52

Figure 5-1 Diagram of Bends in House Connection............53

Figure 5-2 Diagram of Tees with a straight run.............53

Figure 5-3 Diagram of Tees without a straight run..........53

Figure 6-1 Power Duration Curve of Akureyri, Iceland (from 1970 to 1987)..................................54

Figure 6-2 Flow Rate Duration Curve of Akureyri, Iceland (from 1970 to 1987)............................55

LIST OF TABLES

Table 2-1 Average Annual Production from the Exploitation Area of Akureyri District Heating System..........5

Table 4-1 U Values for the Selected System.................12

Table 4-2 Results of Heat Loss Calculation.................14

Table 4-3 Heat Capacity for the Model Buildings............18

Table 4-4 Final Results of Description of Local Buildings..19

Table 5-1 Accuracy of Equations............................24

Table 5-2 Building Parameters..............................26

Table 5-3 Flow Rates of the Pipelines at the Tg = -9°C.....28

Table 5-4 Head Loss Coefficients for Tees..................29

Table 5-5 Results of the Pipeline Network Calculation for the Selected System.............................33

Table 6-1 Power Demand for Six Model Buildings............37

LIST OF SYMBOLS

A : area of item, m^2
$a = (k_1+k_r)/m$ building parameter
$b = k_1/(k_r+k^1)$ building parameter
C : heat capacity of items inside a heated building, kJ/°C
c_j: specific heat of item j inside a building, kJ/kg°C
Cp: heat capacity of water, 4185J/kg°C
D : diameter of the pipe, m
DD(T): annual degree days below temperature T
f : friction factor
h : convective heat transfer coefficient, $W/m^2 {}^\circ C$
k : thermal conductivity, W/m°C; roughness of the pipe
k_1: overall heat loss coefficient of building, W/°C
L : length of pipe, m
m : mass water flow rate, kg/s
m_j: mass of an item contributing to the heat capacity of the building, kg
m_i: flow rate which flows into the node, kg/s
m_o: flow rate which flows out of the node, kg/s
n : air change per hour, 0.8
N_T: number of days in year with mean temperature below T
P_d: total power demand, W
p : pressure drop, P_a
Q : heat loss from building, W
Re: Reynolds number
T : temperature, °C
T_i: room temperature, °C
T_o: outside temperature, °C
T_s: water supply temperature, °C
T_r: water return temperature, °C
U : heat transfer coefficient, $W/m^2 {}^\circ C$
V : water velocity in the pipe, m/s; volume of the heating space in the building, m^3
α : overall effect factors for power demand
ρ : density of water, kg/m^3

1. INTRODUCTION

1.1 Scope of the Work

This report is the final result after six months UNU special training programme in Geothermal Utilization at the National Energy Authority of Iceland and University of Iceland.

The training programme did begin with six weeks introduction lectures on Geothermal Exploration and Utilization. After that, the author got an opportunity to study in the Fjarhitun Consulting Engineering Company and in the Technological Institute of Iceland. Then the author got a course in the University of Iceland on Engineering Heat Transfer, Fluid Mechanics, and Engineering Thermodynamics.

In the beginning of July, the author did inspect the main low and high temperature geothermal areas in the northern and western parts of Iceland. During this exploration trip, the author got some of the practical knowledge about the geothermal energy and geology of Iceland

After the author came back from the field excursion, the author got a special training in the project design of district heating system. During the project design, the author had an opportunity to visit the Icelandic Commission of Standards and some of the Companies in which some of the materials that are used in the district heating system were made or sold. The author went to Akureyri again to collect the data and drawings of the buildings that were used in the author' project design. During 18 september to 20 september, the author attended the lectures which were given by an invited geologist from Hungary (Peter OTTLIK, Geologist).

This report was presented to the UNU as the final results obtained during the six months training program.

In the opinion of the author, Iceland is not only rich in Geothermal Energy, but also has good experience both in its exploration and utilization.

Six months is a short time, but the author got a lot of modern knowledge, both theoretical and practical.

1.2 Purpose of the Study

Geothermal system can be defined and classified on the basis of their geological, hydrological, and heat transfer characteristics. The term " geothermal " refers to the internal thermal energy of the earth; in general it is employed to denote system in which the earth's heat is sufficiently concentrated to form an energy resource (Karlsson, 1982).

Geothermal utilization is divided into high-temperature utilization and low-temperature utilization.

For the low-temperature utilization, one important use is district heating. And it is the largest sector of geothermal energy direct use (Gudmundsson, 1984).

The whole district heating system involves the borehole where the geothermal heat comes from, the pump station, the main transmission pipe, the network pipes which are used to distribute heat water from central location to individual houses and blocks of buildings, and the system of radiators in the buildings.

In this report, a part of the district heating system of Akureyri, Northern Iceland was chosen as the calculation model to study the district heating system.

Purpose of the study was:

- to give the author knowledge about the practices in the design and analysis of the district heating system.

That was done by performing following tasks:

- to analyze a present district heating system,
- to use available standards as a basis for the calculations,
- to evaluate the author' results.

2. DESCRIPTION OF THE SELECTED SYSTEM

2.1 Brief Introduction

The selected district heating system is from Akureyri, in Eyjafjördur, a central northern city of Iceland (Fig.2-1). The latitude is 65°40′ north which is very close to the arctic circle (the arctic circle is 66°32′ north). Population of the city is approximately 13,000. In the year 1977 a new district heating service was established (prior to 1977 the houses in Akureyri were heated by oil firing).

The selected district heating system is located at southwestern part of the city, and includes 14 buildings (Fig.2-2).

2.2 Geothermal Resources of the Selected System

Fig.2-3 shows a schematic picture of the Akureyri district heating system. The energy comes from four geothermal fields. One of them is just outside Akureyri (Glerardalur) while the others (Laugaland, Ytri-Tjarnir and Botn) are in the valley of Eyjafjördur some 12km south of Akureyri (Flovenz 1988).

In Table 2-1, the main geothermal resources of the Akureyri district heating system are shown (Axelsson et al, 1988):

Table 2-1

AVERAGE ANNUAL PRODUCTION FROM THE EXPLOITATION AREAS OF AKUREYRI DISTRICT HEATING SYSTEM

Year	Botn 85 C		Laugaland 95°C		Ytri-Tjarnir 80°C		Glerar-dalur 60°C		Sum	
	l/s	GWh	l/s	GWh	l/s	GWh	l/s	GWh	l/s	GWh
1981	3.8	6.3	82.1	165.7	41.6	62.6	3.3	2.4	130	237
1982	28.5	47.0	65.8	132.8	28.1	42.1	23.4	17.1	146	239
1983	33.0	54.4	50.4	101.7	36.2	54.4	30.0	22.0	149	233
1984	32.7	54.4	38.3	77.3	35.0	52.6	27.3	20.0	133	203
1985	30.8	50.8	39.7	80.1	24.9	37.5	23.1	16.9	118	185
1986	30.3	50.0	30.9	62.3	21.7	32.7	18.8	13.8	102	159
1987	30.6	50.5	34.7	70.0	18.5	27.8	15.6	11.4	99	160
1988		46.8		84.0		29.3		11.2		171
1988-2000	29.0	47.9	46.0	92.9	29.0	43.6	19.0	13.9	123	198

Legend:

1. In calculating the gigawatt-hours (GWh), reference is made to utilization down to a temperature of 40°C.
2. The average annual productions for the years 1988-2000 year are predictions.

2.3 Description of the Geothermal Engineering

2.3.1 Review of the System

There are downhole pumps in all the production wells. The water from Glerardalur field is pumped directly from the boreholes to the central pumping station at Akureyri, and the water from the boreholes at Laugaland, Ytri-Tjarnir and Botn is first pumped to the main pumping station at Laugaland. From the main pumping station at Laugaland, the hot water is pumped through a 500 mm insulated steel pipe to the Akureyri central pumping station.

From the central pumping station at Akureyri the hot water is pumped to the consumers through the distribution network pipes. The water enters the houses at temperature of 70-80°C and leaves the houses at temperature of 30-35°C. Part of the return water from the houses is recycled to the central pumping station and used either as a heat source for the heat pumps or to mix with the 90°C hot water from the production field to cool it down to 80°C.

2.3.2 Borehole Pumps

There are two types of downhole pumps used in the production wells. At Laugaland, Botn and Glerardalur the pumps are at approximately 240 m depth and connected to a motor on the surface by steel axis. At Ytri-Tjarnir where the water level is still lower, a pump with downhole motor is used.

2.3.3 The Main Pumping Station

The water from Laugaland, Ytri-Tjarnir and Botn is collected at the main pumping station at Laugaland, where it is degassed and mixed with Sodium Sulfite to destroy minor contamination of oxygen in the system. This is necessary to prevent corrosion in the system.

2.3.4 The Pipeline to Akureyri

From the main pumping station at Laugaland the water goes through a 500 mm wide and 12 km long steel pipe to the central pumping station at Akureyri, The steel pipe is insulated with water resistant rockwool and coated with aluminum. The pipeline itself is separated into five parts so it is not necessary to empty all the pipeline in case of local maintenance work.

2.3.5 The Central Pumping Station at Akureyri

The pipeline from Laugaland reaches the central pumping station at Akureyri. There the water is mixed with the water from the Glerardalur production field and partly also with the return water from the distribution net in order to regulate the temperature of the water which is pumped to the consumers. Usually the temperature is kept closely to 80°C since higher temperatures can be cause danger of human injury.

2.3.6 The Distribution Net

The distribution net is basically divided into two parts including the upper and lower parts of the city. Part of the water which emerges from the houses is collected and pumped again to the central pumping station but elsewhere it is disposed of to the sea.

2.3.7 The Heat Pumps

The heat pumps consist of two units which together can produce 2.6 MW of power. They extract the residual heat from the return water from the houses and cool it down to 4-15°C. The heat is used to increase the temperature of the 60°C hot water from the Glerardalur production field. The coefficient of performance is somewhat close to 3.5 for the heat pumps.

2.3.8 Reserve Power

In addition to the heat pumps there is an oil fired boiler which can be used in case of emergency. It has seldom been used, mainly in the case of some troubles with the production fields in winter times.

3. WEATHER ANALYSIS

Before a district heating system is planned it is necessary to analyze the local climate. 17 years of weather data (1970-1987) were available. This data was used for the weather analysis to decide the climate parameters of the selected district heating system.

3.1 Cold Wave of the Selected System

A cold wave is defined as a period at least two days for which the outside daily mean temperature is below the system design temperature (Karlsson, 1982).

In the Akureyri, the coldest wave found was in Nov. 1973.

Figure 3-1 shows the diagram of the "cold wave" of the selected system.

3.2 Outside Temperature Duration Curve

Outside temperature duration curve for 17 years is shown in Figure 3-2. In this figure the energy demand for one year (17 years average) can be found, which is equal to the whole area under the curve.

3.3 System Design Temperature

In the district heating system, according to economic reasons, it is important that the temperature which is used to design the system is somewhat higher than the lowest temperature expected for the area. This temperature is called the system design temperature. When the outside temperature falls below the system design temperature, the heating system consumers may for a short time have to live with a little lower inside room temperature than normal.

According to (Karlsson, 1982), the system design temperature can be determined by assuming outdoor temperature constant between all weather observation.

Then the inside temperature can be calculated by:

$$T = T_1 * \exp^{(-at)} + b * T_{Ko} * (1 - \exp^{(-at)}) \qquad (3\text{-}1)$$

where T = Inside air temperature at any time in the period, °C,

T_1 = inside air temperature at beginning of period, °C,

T_{ko} = outside air temperature at end of period, °C

t = time interval between weather observation, (here t is 3 hours or 0.125 days).

b = building heat loss parameter,

$= \Delta T_m / (\Delta T_m + T_i - T_g)$,

a = building heat storage parameter,

$= K_1/(b*m)$,

ΔT_m = log mean temperature difference at T_g,

K_1 = heat loss parameter.

Now assuming $T_g = -9$°C, the indoor temperature can be found using equation (3-1).

The cold wave temperature, that is $T_o - T_g$, is shown on Fig.3-3 together with the drop in indoor temperature. There it can be seen that the indoor temperature will drop about 3°C maximum, which indicates that -9°C is quite acceptable system design temperature. At -9°C outside temperature, the return water temperature is calculated to be $T_r = 34.01$°C.

4. DESCRIPTION OF LOCAL BUILDINGS

In this selected district heating system, six buildings were chosen as representative for the heat loss calculations, and the results of the calculations are used to estimate the total heat loss for the whole selected system.

4.1 Heat Loss Calculation

4.1.1 Calculation of the Heat Transfer Coefficient (U Value)

Formula for calculation U value is expressed as followings:

$$U = \frac{1}{\Sigma 1/h + \Sigma \Delta x/k}, \qquad (4-1)$$

where U = heat transfer coefficient, W/m °C,

h = convective heat transfer coefficient, W/m °C,

Δx = thickness of the calculating layer, m,

k = thermal conductivity, W/m°C.

U values for the selected system are shown in Table 4-1.

Table 4-1

U VALUE FOR THE SELECTED SYSTEM

Items	U
Wall:	0.474
Window:	3.2
Door:	2.5
Floor:	
Inner strip:	0.557
outer strip :	1.004
Ceiling:	0.281
Roof:	3.333

Legend:

1. Unit of the U value is W/m °C.
2. Style of the window is double glazing, spacing of the glass panes is 9mm, 90% areas is glass, which gives U = 3.3, and 10% of the frontal area is window frame, which has U = 2.3, so the U value for the whole window is equal to 90%*3.3+10%*2.3, which equals to 3.2.
3. Inside convection resistance factor:
   $1/h_i = 0.13$, $m^2 \cdot C/W$
   Outside convection resistance factor:
   $1/h_o = 0.04$, $m^2 \cdot C/W$
4. All above calculations are based on Icelandic Standard (IST 66) and Holman (1989).

4.1.2 Calculation of the Heat Loss (Q)

For the wall, window, door, floor (includes inner strip and outer strip), ceiling, and roof, the equation to calculate heat loss through above items is expressed as following:

$$Q = U*A*\Delta T, \qquad (4\text{-}2)$$

where Q = heat loss, W,
U = heat loss coefficient, W/m °C,
ΔT = temperature difference, equal to $T_i - T_o$, °C,
T_i = inside temperature, °C,
T_o = outside temperature, °C.

For calculating heat loss through infiltration, the following equation is used:

$$Q = 0.34*n*v*(T_i - T_o), \qquad (4\text{-}3)$$

where 0.34 = heat capacity per m^3 divided by 3600 seconds per hour,
n = air changes per hour, taken as 0.8,
v = volume of the heating space in the building, m^3,
T_i = inside (room) temperature, °C,
T_o = outside temperature, °C.

Using equation (4-2) and equation (4-3), the heat loss for each building element can be calculated, and the results of the calculations for one sample building are shown in Table 4-2.

Table 4-2

RESULTS OF HEAT LOSS CALCULATIONS

Name of Building: KVISTAGERÐI 1

Items:	$U(W/m^2 \cdot C)$	$A(m^2)$	$V(m^3)$	$\Delta T(^\circ C)$	Q(w)
1. Wall-	0.474			35	
East:		22.24			368.96
West:		22.48			372.96
south:		20.73			343.94
north:		27.14			405.25
2. Window-	3.2			35	
East:		2.96			331.52
West:		3.12			349.44
South:		14.02			1570.24
North:		-----			-------
3. Door-	2.5			35	
East:		2.20			192.50
West:		1.47			128.60
South:		2.20			192.50
North:		----			-----
4. Floor-					
Inner:	0.557	77.02		15	643.50
Outer:	1.004	48.60		35	1707.80
5. Ceiling:	0.281	125.62		32.52	1147.93
6. Roof:	3.333	138.62		2.48	1145.81
7. Infiltration:			314.05	35	5232.00
8. Total Q of above items:					15338.22
9. Cold Wall: (7.5%)					1150.37
10. Total Q:					16488.59

Legend:

1. Temperature difference($\Delta T=T_i-T_o$) for wall, window, door and floor outer strip is equal to 20-(-15), that is 35°C.

2. Temperature difference for floor inner strip is equal to (T_i-T_{ground}), that is 15°C.
3. Temperature differences in ceiling and in roof were found by following method:

   $$Tx = \frac{U1*A1*Ti+U2*A2*To}{U_1*A_1 + U_2*A_2}$$

   Tx = -12.52°C

   so ΔT for ceiling is equal to (T_i-T_x), that is 32.52°C, and ΔT for roof is equal to (T_x-T_o), that is 2.48°C.
4. 3 to 4 cold walls, according to the Icelandic Standard, 7.5% is chosen. And 7.5% multiplied by item 8 is equal to heat loss through the cold wall (item 9).

GARAGE OF KVISTAGERÐI 1

Items:	U(W/m °C)	A(m)	V(m3)	ΔT(°C)	Q(W)
1. Wall-	0.474			30	
East:		17.48			248.60
West:		12.42			76.50
South:		3.63			51.55
north:		7.33			103.23
2. Window-	3.200			30	
West:		5.07			486.70
North:		2.10			201.60
3. Door-	2.500			30	
south:		5.80			435.00
4. Floor-					
Inner:	0.557	21.46		10	119.53
Outer:	1.004	9.70		30	292.20
5. Roof:	0.45	31.16		30	420.66
6. Infiltration:			71.67	30	848.00
7. Total:					3283.57

Legend:

1. This part of the building is a garage, the inside temperature is assumed to be 15°C, so ΔT is equal to 30°C.
2. U value for the garage roof is decided as following:

   From the Icelandic standard, for the roof, if no insulation, U = 3.3. In the garage there is 7cm insulation at the roof, so U value is expressed by following:

   $$1/U = 1/h_i + \Delta x/k + 1/U_i + 1/h_o$$

   $$= 0.13 + 0.07/0.04 + 0.3 + 0.04$$

   $$= 2.22$$

   so U = 1/2.22 = 0.45 W/m °C.
3. In the garage, cold walls are not considered.
4. Total heat loss for the whole building is then 16488.59 + 3283.57 = 19772.2W

The above table shows the calculation of one separate building, the calculating method of other buildings are as same as above table. Final data for the six buildings is shown in Table 4-4.

4.2 Heat Capacity Calculation

The heat capacity of the building is expressed as:

$$C = \Sigma m_j * c_j, \tag{4-4}$$

where C = building heat capacity, kJ/°C,

m_j = mass of an item, kg,

c_j = specific heat, kJ/kg°C.

For the wall, the material is concrete, so the density of the big inside wall is 2500 kg/m^3, and the density of the small inside wall is 1500 kg/m^3.

For the floor, two layers, one is concrete, the other is plaster, so the density of the concrete is assumed to be 2500 kg/m^3, the density of the plaster is equal to 1440 kg/m^3.

Specific heat for the concrete is 0.88 kJ/kg°C, for the plaster is 0.84 kJ/kg°C.

Above analysis depends on IST 66 and Holman (1989).

The results of heat capacity calculations for one sample building are shown in Table 4-3.

Table 4-3

RESULTS OF HEAT CAPACITY CALCULATIONS

Name of the building: KVISTAGERÐI 1 INCLUDING GARAGE

Volume of concrete:

1. Small inside walls:	8.78 m^3
2. Big inside walls:	4.48 m^3
3. Floor:	17.25 m^3
4. Total:	30.51 m^3

Calculation of the heat capacity:

$$C = \Sigma m_j * c_j,$$

$$C = m_1 * c_1 + m_2 * c_2 + m_3 * c_3 + m_4 * c_4,$$

$$\underline{C = 57840.6 \text{ kJ}/^\circ\text{C}.}$$

Legend:

1. The total volume of concrete does not include the outside wall, because the outside wall is insulated on the inside surface, and is therefore cold, no heat capacity of this part is taken into account.
2. For the floor, there is no insulation, so the thermal gradient is linear. Therefore one half is considered cold and the other half is considered warm. So heat capacity of the floor is assumed to be the half of the total amount.
3. The mass of the item (m) is equal to volume of the item multiplied by density of respective item.

Final data for the six buildings is shown in Table 4-4.

4.3 Summary

Table 4-4 summarizes the results of the building calculations.

Table 4-4

FINAL RESULTS

Name of the building: **KVISTAGERÐI 1**

1. Heat loss for the whole building:
   1.1 total heat loss: 19772.2W
   1.2 heat loss per cubic meter space: 51.26W/m^3

2. Total building heat capacity: 57840.6kJ/°C

Name of the building: **KAMBAGERÐI 2**

1. Heat loss for the whole building:
   1.1 total heat loss: 27325.23W
   1.2 heat loss per cubic meter space: 40.2W/m^3
2. Total building heat capacity: 82454.9kJ/°C

Name of the building: **DALSGERÐI 1A**

1. Heat loss for the whole building:
   1.1 total heat loss: 10796.57W
   1.2 heat loss per cubic meter space: 44.48W/m^3

2. Total building heat capacity: 34353.7kJ/°C

Table 4-4 continued.

Name of the building: DALSGERÐI 1B

1. Heat loss for the whole building:

    1.1 total heat loss: 10234.57W
    1.2 heat loss per cubic meter space: 42.17W/m^3

2. Total building heat capacity: 34353.7kJ/°C

Name of the building: GRUNDARGERÐI 6A

1. Heat loss for the whole building:

    1.1 total heat loss: 10219.87W
    1.2 heat loss per cubic meter space: 34.73W/m^3

2. Total heat capacity: 65178.5kJ/°C

Name of the building: GRUNDARGERÐI 6B

1. Heat loss for the whole building:

    1.1 total heat loss: 9332.24W
    1.2 heat loss per cubic meter space: 31.72W/m^3

2. Total heat capacity: 65175.5kJ/°C

---

5. STUDY OF THE DISTRIBUTION SYSTEM

5.1 Calculation of Friction Factor in the Pipes

5.1.1 EQUATION FOR CALCULATING FRICTION FACTOR:

The Colebrook equation (Serghides, 1984) is a widely used method for predicting f, the factor for fluid flow as following:

$$f = (1/(-2.0\log(k/d/3.7+2.51/Re*f^{\frac{1}{2}})))^{-2}, \qquad (5\text{-}1)$$

where f = friction factor,
k = roughness in the pipe, m,
D = internal diameter of the pipe, m,
Re = Reynolds number for flow.

this equation cannot be solved directly, but if one of approximate solution that are explicit in f can be used, the f can be solved directly.

Following, seven equations are discussed to produce the numerical solution which are approximations.

One of the explicit of the equation (5-1) is valid for transitional and turbulent flow Re > 2100 at any relative roughness (K/D) (Serghides, 1984):

$$f = (A-(B-A)^2/(C-2*B+A))^{-2} \qquad (5\text{-}2)$$

where $A = -2.0\log(k/D/3.7+12/Re)$
$B = -2.0\log(k/D/3.7+2.51*A/Re)$
$C = -2.0\log(k/D/3.7+2.51*B/Re)$

The constants A, B, and C are approximation of Equation(5-1) obtained by three iteration of the direct-substitution method.

A simpler version of equation (5-2) is shown as the following. It is still accurate and easier to use for hand calculation.

It is valid for $Re > 2100$ and any value of K/D:

$$f = (4.781-(A-4.781)^{2}/(B-2*A+4.781))^{-2} \qquad (5\text{-}3)$$

where $A = -2.0\log(K/D/3.7+12/Re)$
$B = -2.0\log(K/D/3.7+2.51*A/Re)$

Seven other explicit approximations of the Colebrook equation are given as followings:

Wood equation (Serghides 1984), which is valid for Re 4000 and all K/D:

$$f = 0.094(k/D)^{0.225}+0.53(k/D)+88(k/D)^{0.44}*Re^{a}, \qquad (5\text{-}4)$$

where $a = -1.62(K/D)^{0.134}$.
Moody equation (Serghides, 1984), which is valid for 4000 Re 10^{7} and K/D 0.01:

$$f = 5.5*10^{-3}(1+(2*10^{4}*K/D+10^{6}/Re)^{1/3}) \qquad (5\text{-}5)$$

Jain equation (Serghides, 1984), which is valid for $5000 < Re < 10E+7$ and $0.00004 < K/D < 0.05$:

$$f = (1/(1.14-2.0\log(K/D+21.25/Re^{0.9})))^{2} \qquad (5\text{-}6)$$

Churchill equation (Serghides, 1984), which is valid for all values of Re and K/D:

$$f = 8((8/Re)^{12}+1/(A+B)^{1.5})^{1/12} \qquad (5\text{-}7)$$

where $A = (-2.457\ln((7/Re)^{0.9}+0.27K/D))^{16}$
$B = (37.53/Re)^{16}$

Chen equation (Serghides, 1984), which is valid for all values of Re and K/D:

$$f = (1/-2.0\log(K/D/3.7065-5.0452*A/Re))^2 \qquad (5\text{-}8)$$

where $A = \log((K/D)^{1.1098}/2.8257+5.8506/Re^{0.8981})$

A computer program was made to calculate equation (5-1), (5-2), (5-3), (5-4), (5-5), (5-6), (5-7), (5-8), which assuming values of Re number and K/D to get "f" for respective equation.

The measure of deviation (E) is the fractional difference between the equation's friction-factor value and the numerical solution of the Colebrook equation:

$$E = |(f' - f)/f|, \qquad (5\text{-}9)$$

where E = value of deviation,
f'= the approximation,
f = the Colebrook friction factor as calculated numerically in equation (5-1).

The results of measure of deviation are shown in Table 5-1. for the range of $0.0001 < K/D < 0.05$ and $1000 < Re < 10^8$.

5.2.2 Choice of the Equation to Calculate Friction Factor in the Pipes

From Table 5-1, the equation (5-3) was chosen to use in the pipeline system design according to the results of the measure of deviation as this equation is accurate over a wide range, and is easy to program.

Table 5-1

ACCURACY OF EQUATIONS

Equation	Maximum Deviation(%)
(5-1)	-------
(5-2)	1.4
(5-3)	1.5
(5-4)	5.2
(5-5)	4.5
(5-6)	2.0
(5-7)	2.1
(5-8)	1.5

Legend: Equation (5-1) is the Colebrook-White equation, which is used as reference in equation (5-9).

5.2 Pipeline System Design

5.2.1 Flow Rate for Each House

In the selected district heating system, the supply water temperature is assumed to be 80°C, return water temperature is assumed to be 40°C, so ΔT is equal to 40°C, at -15°C outside temperature.

The steady state rate of the heat loss of a building is given by the equation (5-10):

$$Q = K_1 * (T_i - T_o), \qquad (5\text{-}10)$$

where

Q = heat loss, W,
K_1 = building heat loss coefficient, W/°C,
T_i = room temperature, °C,
T_o = outside air temperature, °C.

From equation (5-10), m can be solved by the equation (5-11)

$$m = Q/(C_p*(T_r-T_s), \qquad (5-11)$$

where

m = flow rate, kg/s,
C_p = heat capacity, 4185J/kg °C,
T_s = water supply temperature, °C,
T_r = water return temperature, °C.

Heat loss (Q) and flow rate (m) for each building of the selected system are found in the Table 5-2.

It has to be noted that these flow rate calculation are based on the Icelandic Building Heat Loss Calculation Standard, and not on experience. The Standard is as usual with such documents conservative, so it is absolutely clear that these flow rates are overestimated.

Table 5-2

BUILDING PARAMETERS

Building No.	Building No.		Size	Load	Flow Rate
Building 1	Kambagerði	2	859	30.0	0.1796
Building 2	Kleifargerði	2	551	19.2	0.1152
Building 3	Kleifargerði	4	572	20.0	0.1196
Building 4	Kleifargerði	1	581	20.3	0.1215
Building 5	Kleifargerði	3	666	23.3	0.1392
Building 6	Kolgerði	1	808	28.2	0.1689
Building 7	Kolgerði	3	1157	40.4	0.2419
Building 8	Kolgerði	2	897	31.3	0.1875
Building 9	Klettagerði	1	820	28.7	0.1714
Building 10	Klettagerði	2	624	21.8	0.1305
Building 11	Klettagerði	3	652	22.8	0.1363
Building 12	Klettagerði	4	696	24.3	0.1455
Building 13	Klettagerði	5	603	21.1	0.1261
Building 14	Klettagerði	6	912	31.9	0.1907

Legend:

Size: Building Volume [m^3]

Load: Heat Load at -15°C [KW]

Flow Rate: Calculated by Equation (5-11), [Kg/s]

5.2.2 Flow Rate for Each Pipe

In this selected system, there are 27 different pipes. Fig.2-2 shows schematic of the system.

In a pipe network, for each node:

$$\Sigma m_i = \Sigma m_o, \qquad (5\text{-}12)$$

where

m_i = flow rate which flows into the node, Kg/s,

m_o = flow rate which flows out of the node, kg/s.

Using the data from table 5-3 and the equation (5-12), the flow rate for each pipe can be calculated. As the system design temperature has been found to be -9°C, the flow rates can be recalculated for every house, and flow rates for every pipe determined according to the geometry of the system. Table 5-3 shows the corrected flow rates.

Now -9°C is used to calculate heat loss and flow rate for each pipe again. The equation is as followins:

$$m_{-9} = Q*(20-(-9))/(20-(-15))/(C_p*\Delta T) \qquad (5\text{-}40)$$

where m_{-9} = flow rate in -9°C as system design temperature, kg/s,

ΔT = $T_s - T_r$, °C, which T_s is water supply temperature, 80°C, T_r is water return temperature, 34.01 °C,

C_p = heat capacity of the water, 4185J/kg°C.

Table 5-3

FLOW RATES OF THE PIPELINES AT Tg = -9°C

Pipe number	Flow rate [kg/s]	Pipe number	Flow rate [kg/s]
1	0.1044	15	0.1399
2	0.1580	16	0.3403
3	0.1205	17	1.2418
4	0.2738	18	0.1006
5	0.3830	19	0.1153
6	0.1129	20	0.2160
7	0.4959	21	0.0990
8	0.1420	22	0.3151
9	0.6380	23	0.0954
10	0.1081	24	0.4105
11	0.7461	25	1.6524
12	0.1553	26	0,1488
13	0.9014	27	1.8012
14	0.1996		

5.2.3 Calculation of the Number of Bends and Z_{bend}

For each house connection, two bends are needed to connect the main pipe and the radiator system in the house (Fig.5-1). And in the pipeline network diagram (Fig.2-2), the number of bends in the system can be found.

From (Beitz and Kuttner, 1986), $Z_{bend} = 0.3$.

5.2.4 Calculation of the Number of Tees

In this pipeline network, there are two different kinds of T_{joints} (shown in Fig. 5-2, and Fig. 5-3).

In the T_{joints} shown in Fig.5-2, there are one T_{run} and one T_{side}.

In the T_{joints} shown in Fig 5-3, there are two T_{side} and no T_{run}.

According to above analysis and (Beitz and Kuttner, 1986), head loss coefficients for run and side can be found, and are shown in the Table 5-4.

Table 5-4

HEAD LOSS COEFFICIENTS FOR Tees

Number of Pipe	Va/V	Run	Side
4	0.433(0.57)	-0.05(-0.07)	0.89(0.95)
5	0.73	0.14	1.02
7	0.23	-0.08	0.88
9	0.22	-0.08	0.88
11	0.145	-0.05	0.91
13	0.172	-0.06	0.90
16	0.41(0.59)	0.07(-0.05)	0.95(0.89)
17	0.27	-0.08	0.88
20	0.47(0.53)	0.01(0.01)	0.92(0.92)
22	0.68	0.14	1.02
24	0.23	-0.08	0.88
25	0.25	-0.08	0.88
27	0.081	0.01	0.91

5.2.5 Calculation of the Required Diameter of the Pipe

Formula for calculation of the required D is expressed as following:

$$D = (4*m/(\pi*v*\rho))^{1/2} \qquad (5\text{-}13)$$

where m = flow rate, kg/s,

v = water velocity in the pipe, m/s,

D = required diameter of the pipe, m,
ρ = density of water, 970.2 kg/m^3.

Here assuming $v = 1$ m/s, and if supply water temperature is 80°C, from (Holman, 1989), ρ and μ can be found,

$\rho = 970.2\ kg/m^3$,
$\mu = 3.47\ kg/m\ s$.

Using equation (5-13), required D can be found. The results are shown in Table 5-5.

5.2.6 Choice of the Nominal Pipe Diameter

The actual diameter of the pipe was used for all calculations, although it was smaller than the required diameter in same pipes.

5.2.7 Calculation of the Area of the Cross Section of the Pipe

Formula for calculation of the area of the transverse section of the pipe is expressed as following:

$$A = \pi * D^2/4, \qquad (5\text{-}14)$$

where A = area of the transverse section of the pipe, m^2,
D = nominal diameter of the pipe, m.

5.2.8 Calculation of the Water Velocity

Water velocity in the pipe is expressed as equation (5-15):

$$V = m/(\rho * A), \qquad (5\text{-}15)$$

where V = water velocity of the pipe, m/s,
m = flow rate, kg/s,

A = cross sectional area of the pipe, m^2,
ρ = density of water, 970,2 kg/m^3(for 80°C water).

5.2.9 Determination of the Reynolds Number (Re):

Re number is expressed as following:

$$Re = \rho*v*D/\mu, \qquad (5\text{-}16)$$

where Re = Re number,
ρ = density of water, 970.2 kg/m^3 (for the 80°C supply water),
v = water velocity of the pipe, m/s,
D = chosen diameter of the pipe, m,
μ = dynamic viscosity, 3.75 kg/ms.

5.2.10 Determination of Roughness (K) of the Pipe

From the Moody Diagram, for commercial steel pipe which was used in the selected system, $K = 0.00005$ m (Olson, 1973). This is valid for new pipes, but in order to account for increase in roughness during the operation of the system, $K = 0.00015$ m was used in the pipeline calculation.

5.2.11 Calculation of the Friction Factor in the Pipes

In chapter 5.1, nine different equations are calculated and compared. Now the best equation (5-3) was chosen to calculate the friction factor of the pipeline in this selected system.

5.2.12 Pressure Drop in the Pipes

Formula of the calculation pressure drop in the pipeline is expressed as following:

$$\Delta p1 = L*f*\rho*v^2/(2*D) \qquad (5\text{-}17)$$

where Δ_{p1} = pressure drop in the pipeline, Pa,

L = length of the respective pipe, m,

f = friction factor,

v = water velocity of the respective pipe, m/s,

D = diameter of the respective pipe, m.

ρ = water density, 970.2 kg/m^3.

5.2.13 Pressure Drop in the Fittings

In this selected system, Δ_p in the fittings contains Z(bend), Z(Trun) and Z(Tside).

Formula for calculating Δ_p in the fittings is expressed as the following:

$$\Delta_{p2} = 1/2*\rho*v^2*\Sigma Z, \quad (5\text{-}18)$$

where Δ_{p2} = pressure drop in the fittings, Pa,

v = water velocity of the respective pipe, m/s,

ΣZ = sum of Z(bend), Z(run) and Z(side),

ρ = water density, 970.2 kg/m^3.

5.2.14 Total Pressure Drop in the Selected System

The total pressure drop for the selected system is equal to:

$$\Delta_p = \Delta_{p1} + \Delta_{p2}, \quad (5\text{-}19)$$

where Δ_p = total pressure drop for the selected system, Pa,

Δ_{p1}= pressure drop in the pipe, Pa,

Δ_{p2}= pressure drop in the fittings, Pa.

And the pressure drop per kilometer is expressed as equation (5-20):

$$\Delta_p/\text{km} = \Delta_p/L*1000/100000, \quad (5\text{-}20)$$

where Δ_p/km = pressure drop per kilometer, bar/km,
Δ_p = total pressure drop of the selected system, Pa,
L = length of the respective pipe, m.

Results for all of above calculations are shown in Table 5-5.

Table 5-5

Results of Pipeline Network Calculation for Selected System

---

pipe#	L[m]	[kg/s]	[kg/s]	D[m]	D[m]	[Pa]	[bar]
1	34	0.126	0.104	0.012	0.022	2507.1	0.74
2	29	0.191	0.158	0.014	0.022	4751.1	1.64
3	27	0.146	0.121	0.013	0.022	2629.3	0.97
4	8	0.336	0.279	0.019	0.027	1272.5	1.59
5	10	0.462	0.383	0.022	0.027	2743.2	2.74
6	18	0.136	0.113	0.012	0.022	1546.4	0.86
7	32	0.599	0.496	0.026	0.036	3383.6	1.06
8	18	0.171	0.142	0.014	0.022	2402.7	1.33
9	5	0.770	0.638	0.029	0.036	849.2	1.70
10	19	0.131	0.108	0.012	0.022	1500.4	0.79
11	38	0.901	0.746	0.031	0.036	9004.0	2.37
12	19	0.188	0.155	0.014	0.022	3013.5	1.59
13	37	1.088	0.901	0.034	0.036	12580.4	3.40
14	58	0.241	0.200	0.016	0.022	14816.7	2.55
15	10	0.169	0.140	0.014	0.022	1340.2	1.34
16	10	0.411	0.340	0.021	0.027	2311.2	2.31
17	17	1.499	1.242	0.040	0.042	4876.2	2.87
18	2	0.122	0.101	0.011	0.022	158.7	0.79
19	27	0.139	0.115	0.012	0.022	2399.8	0.89
20	26	0.261	0.216	0.017	0.022	7838.8	3.01
21	37	0.120	0.099	0.011	0.022	2463.1	0.67
22	25	0.380	0.315	0.020	0.022	15495.4	6.20
23	15	0.115	0.095	0.011	0.022	937.9	0.63
24	10	0.496	0.411	0.023	0.027	3331.9	3.33
25	23	1.994	1.652	0.047	0.042	11596.3	5.04
26	25	0.180	0.149	0.014	0.027	1112.7	0.45
27	55	2.174	1.801	0.049	0.042	33052.9	6.01

5.2.15 Analysis of Results

The total pressure drop in each pipeline is shown in Table 5-6. These results show high pressure drop, over the limit imposed by (Karlsson, 1984). As previously explained in 5.2.1., this is due to the conservative calculation procedure imposed by (Icelandic Standard IST 66). When the fact that the really experienced water consumption lies well below the calculated values, the pressure drop can well be estimated to be within limits.

6. STUDY OF THE SUPPLY SYSTEM

6.1 Water Supply Situation

6.1.1 Toltal Selected District Heating System Power Demand

In order to calculate the heat requirements for the selected system, one method is chosen to do it, that is heating requirements based on the volume of buildings.

From chapter 4 (heat loss calculation), the heat loss per cubic space meter for each model house is determined. But this figures do not include the heat loss in the distribution network as well as the requirements for hot water tap use and so on.

Followings, some of the effects of heat loss and correction factors are mentioned.

-Heat losses in building pipe network. It is estimated that 5-10% of heat supplied to ordinary hot water central heating system is lost.

-Heat loss in the distribution network. 5% is used in Iceland, when estimating the district heating power demand.

-Effects of solar radiation. The solar radiation in spring, summer, and fall provide for approximately 10% of the annual heating needs. For this reason the heating system power demand is increased by 10% in order to account for this effect.

-Change of heating habits. Peoples heating habits change with the advent of district heating in such a way that power demand may be increased by 10 to 15%. This is because the geothermal district heating cost is favorable in comparison with fuel heating cost.

-Increased heat demand due to strong wind. Strong wind will increase the heat demand of building, it is estimated that 10% of the heat demand will take care of this extra load on the heating system.

-Overall correction factors. Above list all the effects of district heating demand. The correction factor is combined, the overall correction factor can expressed as following:

$$\alpha = 1.05\ 1.05\ 1.1\ 1.12/1.1 \qquad (6\text{-}1)$$

$$\alpha = 1.23$$

The total power demand for each model house can be calculated as follows:

$$Pd = \alpha * Q * v, \qquad (6\text{-}2)$$

where Pd = total power demand for each model house, W,
α = overall effect factors, 1.23,
Q = heat loss for each model house, W/m^3,
v = heating space for each model house, m^3.

Using equation (6-2), the power demand for each model building can be found. The results are shown in Table 6-1.

Table 6-1

POWER DEMAND FOR SIX MODEL BUILDINGS

Name of building	$Q(W/m^3)$	$V(m^3)$	Pd(W)
KAMBAGERÐI 2	40.20	859	33623.28
KVISTAGERÐI 1	51.26	475	24337.22
DALSGERÐI 1A	44.48	299	13294.62
DALSGERÐI 1B	42.17	299	12604.19
GRUNDARGERÐI 6A	34.73	362	12559.06
GRUNDARGERÐI 6B	31.72	362	11470.59

In this table four block buildings were calculated, but they are not in the selected system. Only first two values (for the individual houses) were used to decide the power demand for the whole selected system. From Table 5-2, groups of houses can be found according to the size, one is with building volume around 800-1000m^3, another is with building volume around 500-600m^3, so the first two heat values in Table 6-1 were used to describe the two different sizes in Table 5-2. Adding the power demand for all buildings, the total power demand for the whole selected system can be found:

Total power demand for the selected system: 363.3KW

The Fig. 6-1 shows the power duration.

6.1.2 Determination of District Heating Water Supply

In order to calculate water supply, following equation is used:

$$m = Q/(Cp*(Tr-Ts)), \tag{6-3}$$

where m = total flow rate, kg/s,
Q = total heat loss, w,
C_p = heat capacity of water, 4185J/kg°C,
T_s = water supply temperature, °C,
T_r = water return temperature, °C.

Using equation(6-3),

Total water supply for the selected system: 2.17kg/s

6.2 Possibilities of Reducing Water Consumption

Saving water resources is important when the district heating system is designed. Using 80/35°C, -15°C radiator system instead of 80/40°C, -15°C system will save water. In this way the water consumption can be reduced.

According to results of calculation shown in Figure 6-2, the total water volume used per year by the 80/40 -15°C system is 27140.35m^3/year, and the total water volume used per year by the 80/35 -15°C system is 26000.84m^3/year, which is reduction by about 4% of water volume.

One problem is that the radiators becomes larger and more expensive. The radiator area can be calculated from the following equation:

$$Q = K*A*\Delta T_m{}^{4/3}, \qquad (6-4)$$

where Q = heat loss from building, W,
K = the radiator heat transfer correction coefficient, W/(°C)$^{4/3}$,
A = the radiator surface area, m^2,
ΔT_m= the logarithmic mean temperature difference between the radiator water temperature and the room air temperature, °C.

If $Q_{80/40} = Q_{80/35}$, and assuming $Q_{80/40} = Q_1$, $Q_{80/35} = Q_2$ then the following equation can used:

$$A_1/A_2 = (\Delta T_{m1}/\Delta T_{m2})^{4/3} \qquad (6-5)$$

And also ΔT_m = can be expressed as follows:

$$\Delta T_m = (T_f - T_b)/(\ln(T_f - T_i)/(T_b - T_i)) \qquad (6-6)$$

where T_f = inflow water temperature to radiators, °C,
T_b = return water temperature from radiators, °C,
T_i = room temperature, °C.

For the 80/40, -15°C system:

$$\Delta T_m = (80-40)/(\ln(80-20)/(40-20))$$

$$= 36.4\ ^{\circ}C$$

For the 80/35, -15°C system:

$$\Delta T_m = (80-35)/(\ln(80-20)/(35-20))$$
$$= 32.5\ ^{\circ}C$$

For the 80/30, -15°C system:

$$\Delta T_m = (80-30)/(\ln(80-20)/(30-20))$$
$$= 27.9\ ^{\circ}C$$

And the total water volume consumed per year,

For the 80/40, -15°C system is 27140.35m^3,

For the 80/35, -15°C system is 26000.84m^3,

For the 80/30, -15°C system is 22526.21m^3.

So for the 80/35°C system, the radiator area increase is,

$$A_1/A_2 = (36.4/32.5)^{4/3}$$
$$= 1.16$$

which means 16% increase, the water volume reduction is,

$$(27140.35-26000.84)/27140.35 = 4\%$$

For the 80/30, -15°C system, the area increase is,

$$A_1/A_2 = (36.4/27.9)^{4/3}$$
$$= 1.42$$

which means 42% increase, the water volume reduction is,

$$(27140.35-22526.21) = 17\%$$

This can be form a basis for an economic analysis if the water prices can be estimated.

Fig. 6-2 shows the flow rate duration curve for the three radiator systems.

6.3 Possibilities of Increasing the Water Supply

Saving energy is also important when a district heating system is designed. Using Heat Pump to utilize the heat from the return water is one way to save energy.

7. DISCUSSION AND CONCLUSION:

- In the heat loss calculation for each building, -15°C was used as the outside temperature (according to Iceland Standard). But from the weather analysis, there are only 0.6 days per year for the average year which temperature is below -15°C, which means that this system design temperature would lead to an unreasonable expensive design without giving the consumer any real benefit. When using -9°C as system design temperature, it can be found that 11.4 days per year will have temperature below -9°C. Our calculation in chapter 3 shows that the indoor temperature will be acceptable at any time for the system design temperature. This change will decrease the system investment, which is quite economic.

- Chosen D in some pipes is less than required D. That is because this selected district heating system is an actual system, which has been designed according to experience. On the other hand, these calculations here use the Icelandic Standard (IST 66), which does not take actual local circumstances into account.

All calculations here have used the real diameters.

- In pipeline calculation, some problems were found, that is the total pressure drop in some pipe is too high (usually pressure drop in a straight section of the pipe is on the order of 0.5-1.0 bar/km). This is due to the same reason as previously mentioned.

- Study of district heating system is good practice to know low temperature utilization of geothermal energy.

- Unfortunately, time is not enough to study the whole district heating system. But this is good beginning for the author to study district heating system deeply in the future.

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REFERENCES

Axelsson Guðni, Tulinius Helga, Flovenz Olafur G. and Thoroddsen Thorsteinn (1988): Vatnsöflun Hitaveitu Akureyrar (in Icelandic): ORKUSTOFNUN Report, 33pp.

Beitz W. and K. H.Kuttner (1986): Dubbels Taschenbuch fur den Maschinenbau (in German): Springer-Verlag, Berlin, 1498 pp.

Flovenz Olafur G. (1988): Short notes on the Akureyri District Heating and Geothermal Field in Eyjafjörður, North Iceland: UNU Geothermal Training Program, Seleted Papers on Geothermal Energy in Iceland, 3-14 July, 1989.

Gudmundsson J. S. (1984): Direct Uses of Geothermal Energy in 1984: Geothermal Resources Council, 1985 International Symposium on Geothermal Energy, Int. Vol.,1985, p 19 - 29.

Holman J. P. (1989): Heat transfer: McGraw-Hill, New York 676 pp.

Karlsson Thorbjörn (1982): Geothermal District Heating, the Iceland Experience: UNU Geothermal Training Program, Iceland, Report, 1982-4, 116 pp.

Olson Reuben M. (1973): Essentials of Engineering Fluid Mechanics: Intext Educational Publishers, New York, 637 pp.

Rybach L. and L.J.P.Muffler (1981): Geothermal Systems: Publish, John Wiley and Sons, New York, 359 pp.

Serghides T.K. (1984): Estimate Friction Factor Accurately: Chemical Engineering, March 5,1984, 63-64 pp.

IBM Corp. (1984): BASIC Reference (1984), 378 pp.

Icelandic Standard IST 66 (in Icelandic): 1975 Issue 1.

APPENDIX I. Computer Programme-Calculation of Heat Transfer Coefficient (U):

```
10 PRINT"Programme1-Calculation of Heat Transfer Coeffient (U)"
20 PRINT
30 INPUT"How many layers (n)?  ";N
40 PRINT : PRINT
50 FOR I=1 TO N
60 PRINT USING "##";I;
70 PRINT ". layer"
80 PRINT
90 INPUT"k is consisted by the same material? (y/n)?";REPLY$
100 IF REPLY$="n" OR REPLY$="N" THEN GOSUB 290
110 INPUT " k factor for layer.....:"; M(I,1)
120 INPUT " Thickness of the layer.:"; M(I,2)
130 PRINT : PRINT
140 NEXT I
150 PRINT
160 INPUT " Inside resistance factor..:"; RI
170 INPUT " Outside resistance factor.:"; RO
180 INPUT " Ground resistance factor..:"; RG
190 R=RI+RO+RG
200 PRINT
210 FOR J=1 TO N
220 R=R+M(J,2)/M(J,1)
230 NEXT J
240 U=1/R
250 PRINT "--------------------------------------------------"
260 PRINT "The total resistance is [m^2*°C/W]...........:";R
270 PRINT "The heat transfer coefficient is [W/m^2*°C]..:";U
280 END
290 INPUT "the area of first material";A1
300 INPUT "the area of second material";A2
310 INPUT "the k valume of first material";K1
320 INPUT "the k valume of second material";K2
330 K=(A1*K1+A2*K2)/(A1+A2)
340 PRINT "k=";K
350 RETURN
```

APPENDIX II. Computer Programme-Calculation and Comparison of Friction Factor

```
10 PRINT"Programme2-Calculation and Comparision of Friction in the Pipeline"
20 PRINT
30 OPEN "o",#1,"DATA.PRN"
40 FOR K=.0001 TO .05 STEP .005
50 FOR II=4 TO 8
60 RE=10^II
70 PRINT
80 PRINT "-----------------------------------------------------------------
90 PRINT "k/d","Re","F in Eq1","F in Eq2","F in Eq3"
100 PRINT "----------------------------------------------------------------
110 PRINT
120 F=.02
130 E=1
140 WHILE E>.0005
150 IF RE<100 THEN GOTO 200
160 F1=(1/(-2*LOG(K/3.7+2.51/(RE*F^(1/2)))/LOG(10)))^2
170 E=ABS((F1-F)/F1)
180 F=F1
190 WEND
200 IF RE<2100 OR RE>1E+07 THEN GOTO 250
210 A=-2*LOG(K/3.7+12/RE)/LOG(10)
220 B=-2*LOG(K/3.7+2.51*A/RE)/LOG(10)
230 C=-2*LOG(K/3.7+2.51*B/RE)/LOG(10)
240 F2=(A-(B-A)^2/(C-2*B+A))^-2
250 IF RE<2100 THEN GOTO 290
260 A=-2*LOG(K/3.7+12/RE)/LOG(10)
270 B=-2*LOG(K/3.7+2.51*A/RE)/LOG(10)
280 F3=(4.781-(A-4.781)^2/(B-2*A+4.781))^-2
290 PRINT K,RE,F1,F2,F3,
300 PRINT
310 PRINT"-----------------------------------------------------------------
320 PRINT "k/d","Re","F in Eq4","F in Eq5"
330 PRINT"-----------------------------------------------------------------
340 PRINT
350 RE=10^II
360 IF K<=.01 AND RE<=10^7 AND RE>=4000  THEN F5=.0055*(1+(20000*K+1000000!/
370 IF RE<4000 THEN GOTO 400
380 P=-1.62*(K)^.134
390 F4=9.399999E-02*K^.225+.53*K+88*K^.44*RE^P
400 IF RE<4100 THEN GOTO 410
410 PRINT K,RE,F4,F5
```

```
420 PRINT
430 PRINT"------------------------------------------------------------------
440 PRINT "K/D","Re","F in Eq6","F in Eq7","F in Eq8"
450 PRINT"------------------------------------------------------------------
460 PRINT
470 NN=1
480 F=.02
490 E=1
500 WHILE E>=.001
510 IF RE<5000 OR RE>10000000# THEN GOTO 660
520 F6=(1/(1.14-2*LOG(K+21.25/RE^.9)/LOG(10)))^2
530 C=(-2.457*LOG((7/RE)^.9+.27*K))^16
540 D=(37.53/RE)^16
550 F7=8*((8/RE)^12+1/(C+D)^1.5)^(1/12)
560 A=LOG(K^1.1098/2.8257+5.8506/RE^.8981)/LOG(10)
570 F8=(1/(-2*LOG(K/3.7065-5.0452*A/RE)/LOG(10)))^2
580 E=ABS((F-F6)/F6)
590 E=ABS((F-F7)/F7)
600 E=ABS((F-F8)/F8)
610 NN=NN+1
620 F=F6
630 F=F7
640 F=F8
650 WEND
660 PRINT K,RE,F6,F7,F8
670 PRINT
680 PRINT"------------------------------------------------------------------
690 PRINT "K/D","Re","F in Eq9","NN"
700 PRINT"------------------------------------------------------------------
710 PRINT
720 NN=1
730 F=.02
740 E=1
750 WHILE E>=.001
760 IF RE<10^7 THEN GOTO 830
770 B=LOG(K/3.7-5.02/RE)/LOG(10)*LOG(K/3.7+13/RE)/LOG(10)
780 F9=(1/(-2*LOG(K/3.7-5.02*B/RE)/LOG(10)))^2
790 E=ABS((F-F9)/F9)
800 NN=NN+1
810 F=F9
820 WEND
830 PRINT K,RE,F9,NN
840 PRINT#1,K;RE;F1;F2;F3;F4;F5;F6;F7;F8;F9
850 NEXT II
860 NEXT K
870 PRINT
880 PRINT"------------------------------------------------------------------
890 CLOSE#1
900 END
```

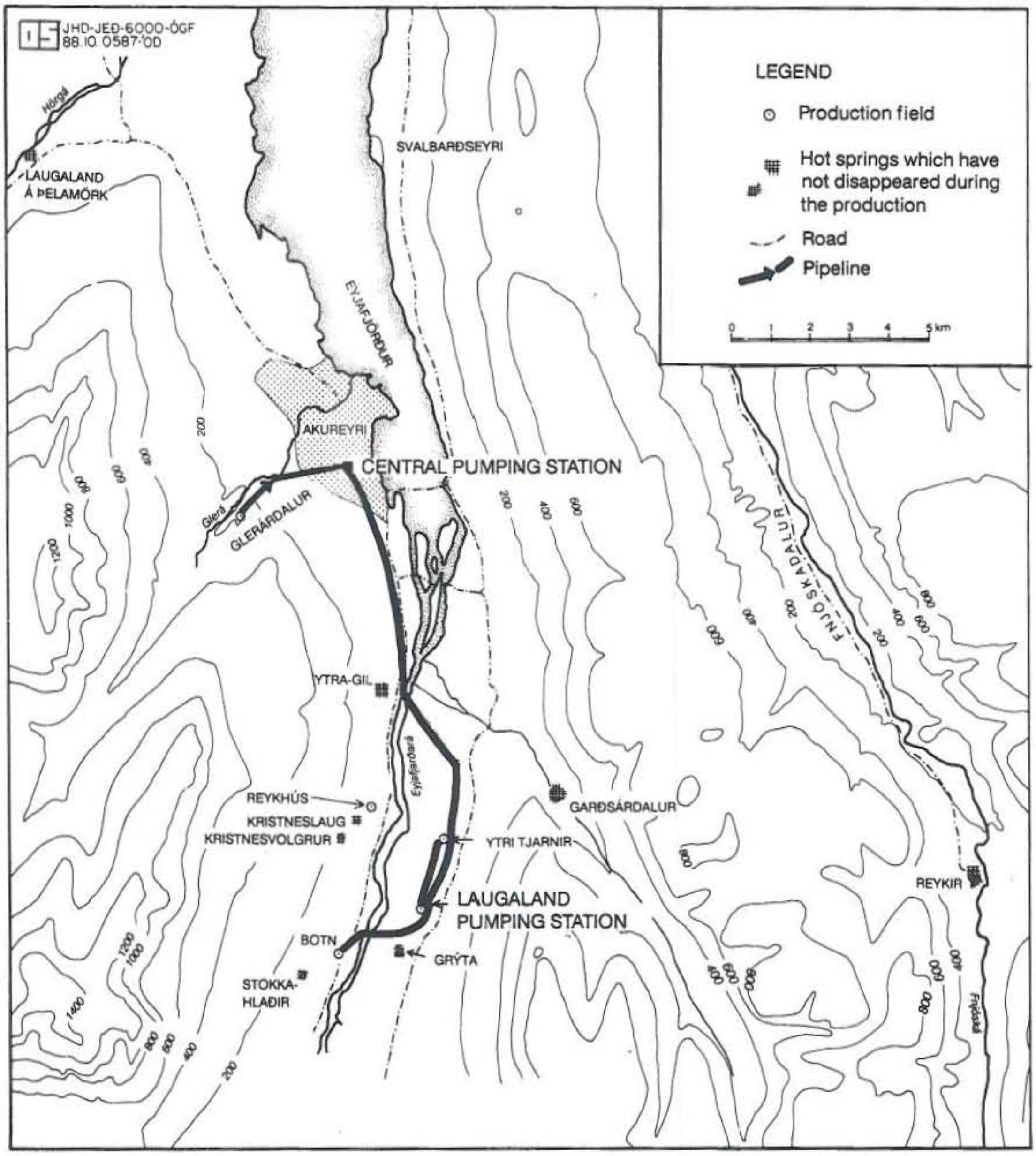

Fig. 2-1 Akureyri City and Geothermal Fields

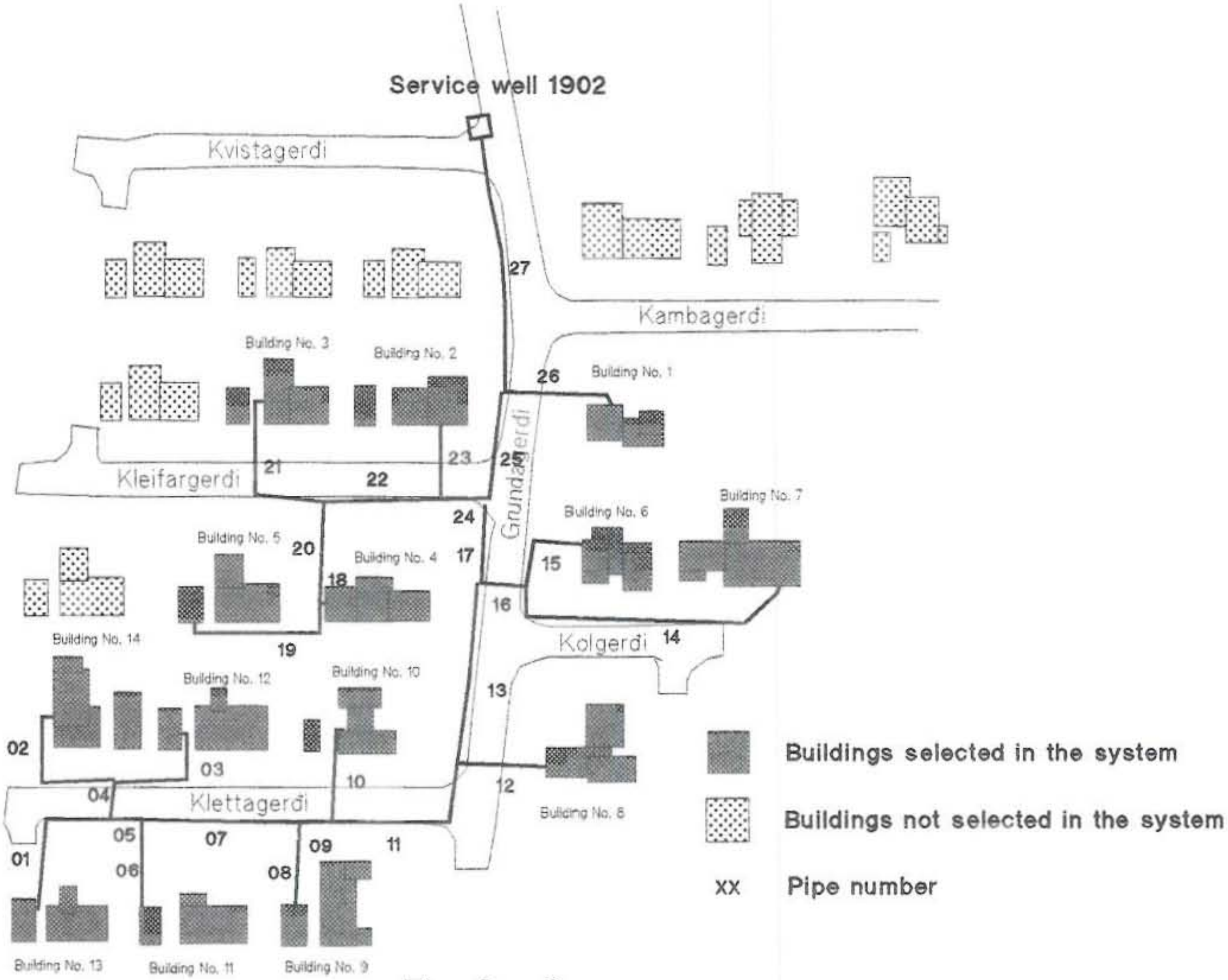

Fig. 2 – 2

Selected system of a part of Gerðahverfi II, Akureyri

Fig. 2-2 Selected System of a part of Gerdahverfi II, Akureyri

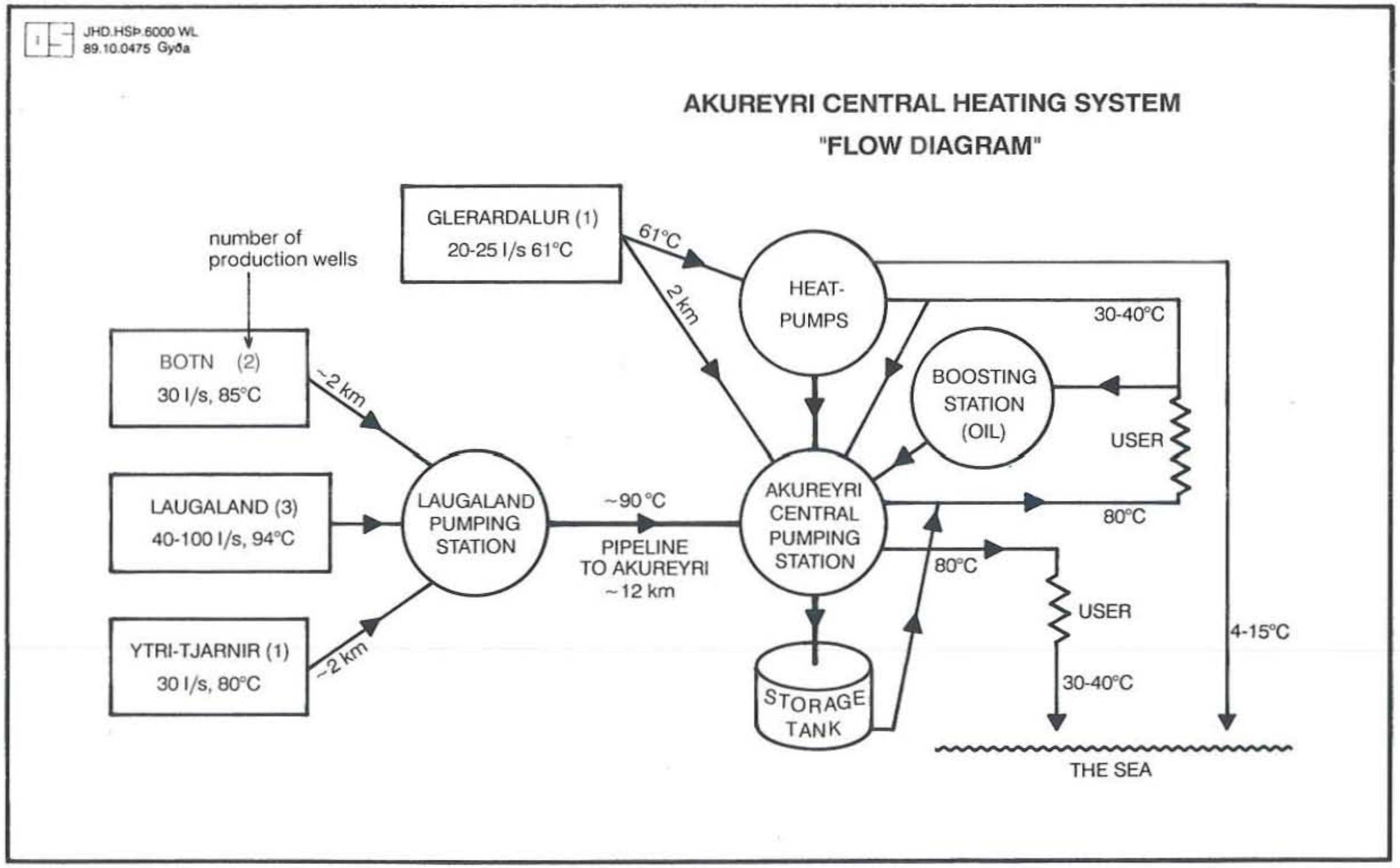

Fig. 2-3 Akureyri Central Heating System

Fig. 3-1

Ambient temperature during a cold spell

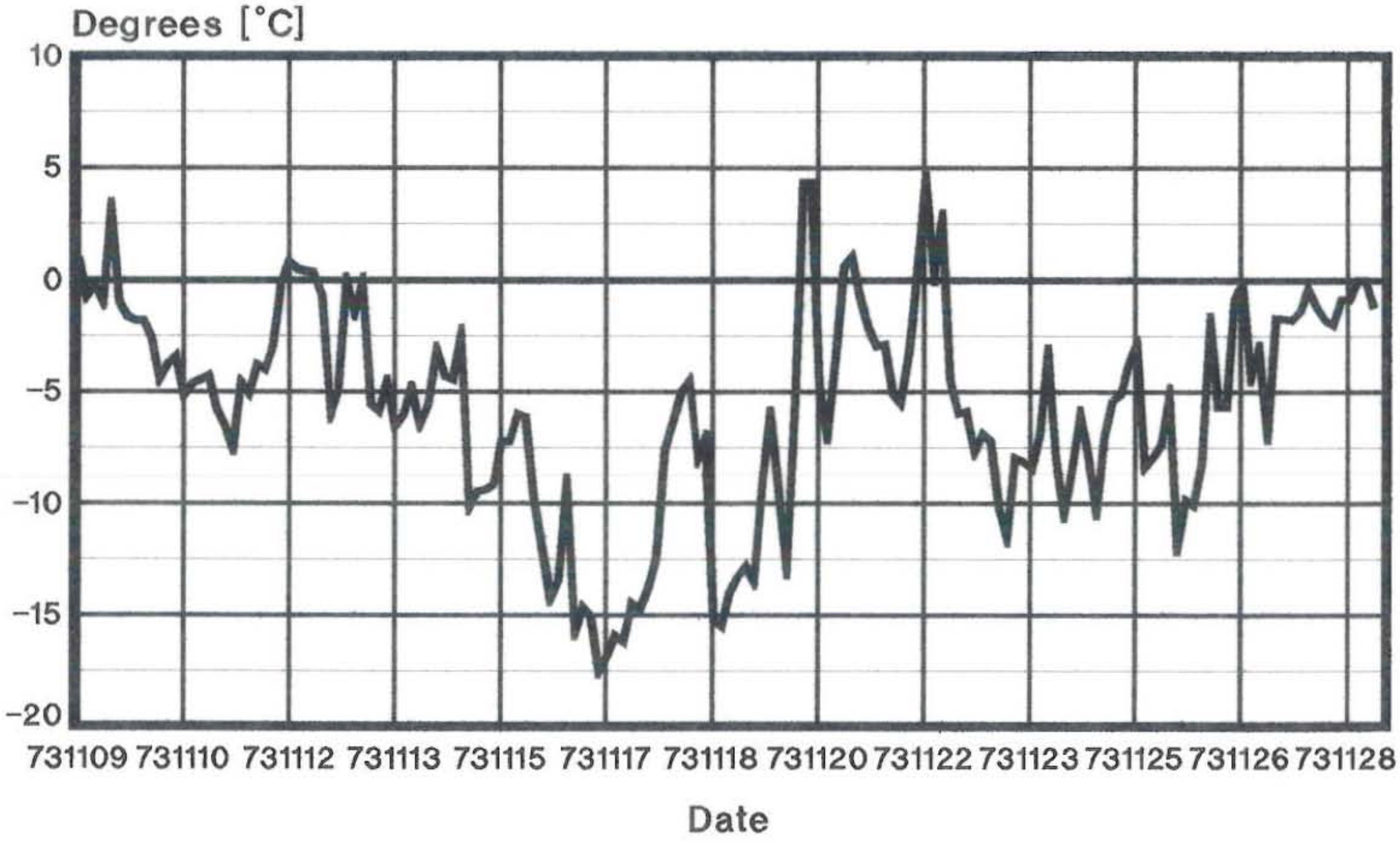

Fig. 3-1 Ambient Temperature During a Cold Spell

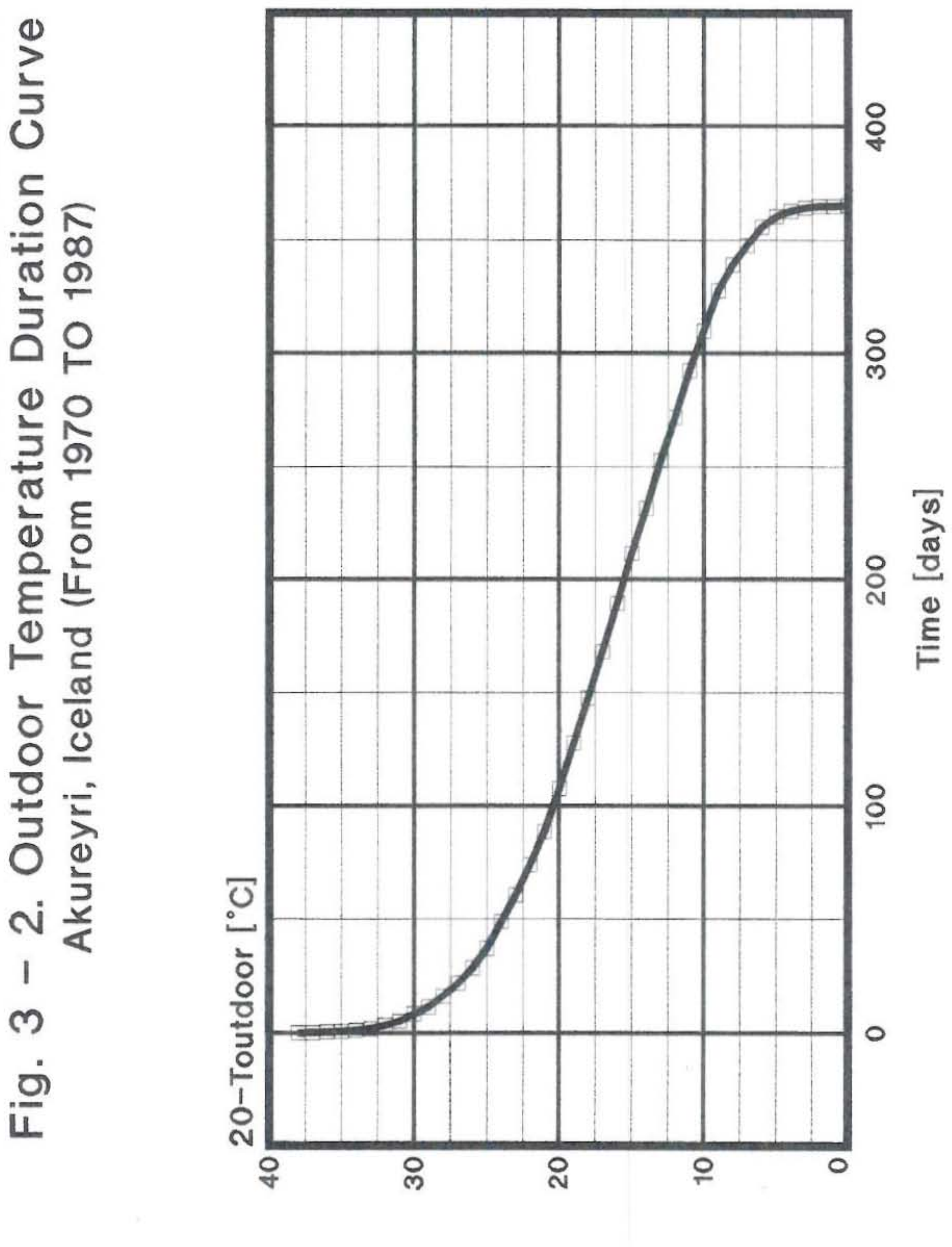

Fig. 3-2 Outside Temperature Duration Curve
of Akureyri, Iceland (from 1970 to 1987)

Fig. 3-3.

Ambient temp. below Tg and drop in Inside Temperature

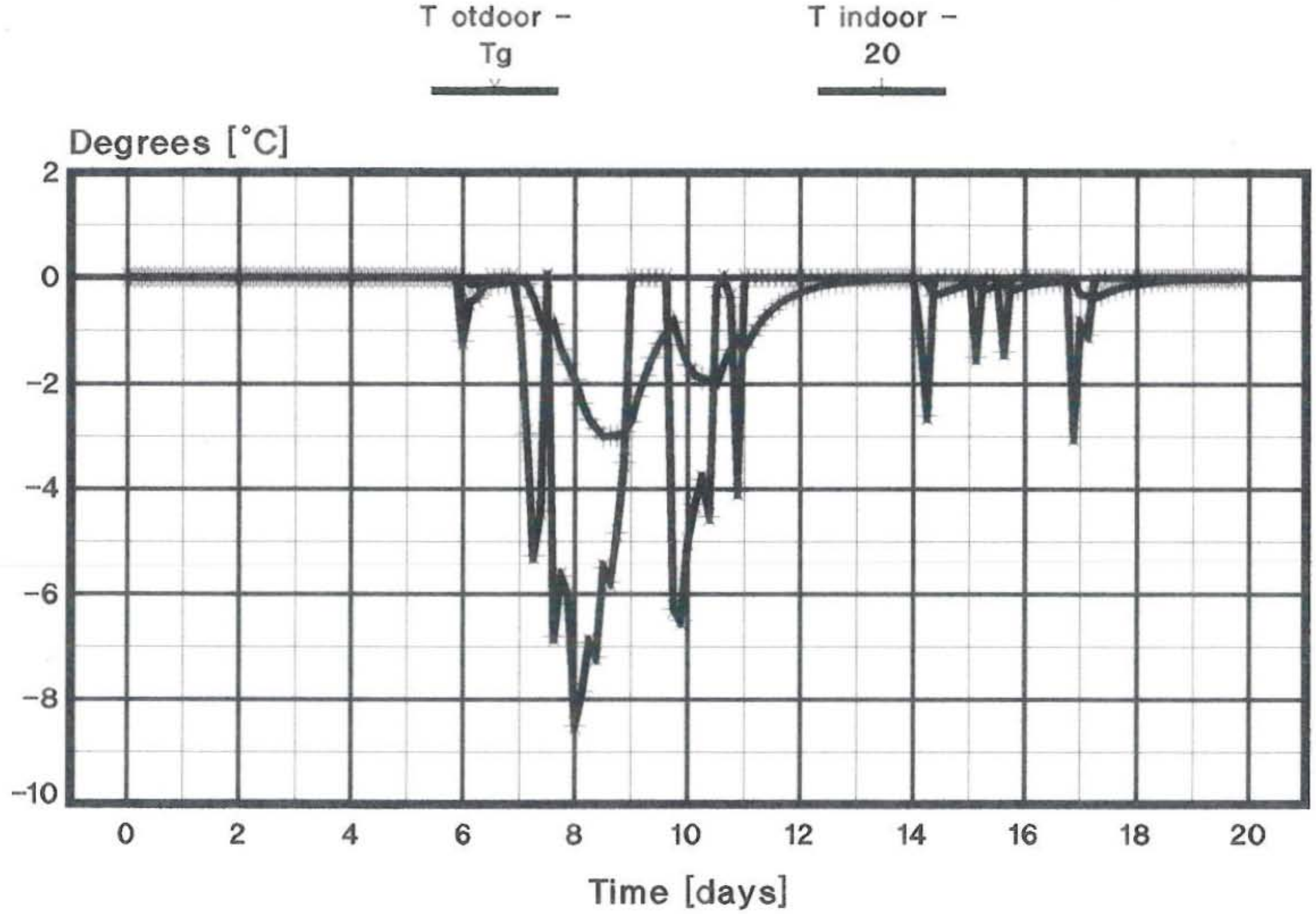

Fig 3-3 Ambient Temperature Below Tg
and Drop in Inside Temperature

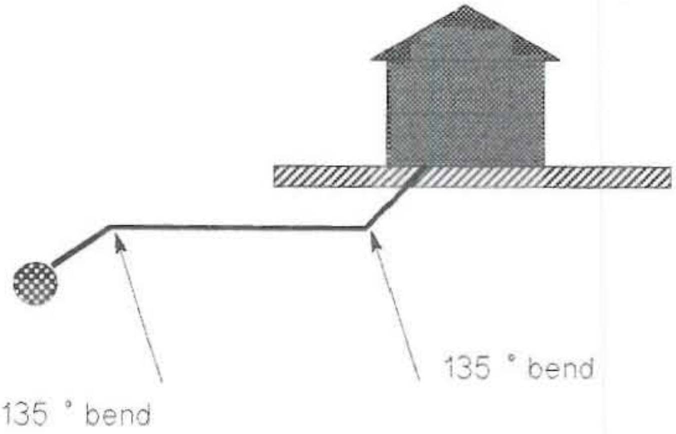

Fig. 5 − 1

Diagram of bends in house connection

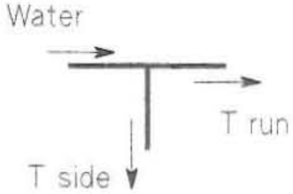

Fig. 5 − 2

Diagram of Tees with a straight run

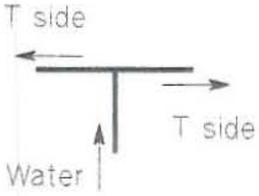

Fig. 5 − 3

Diagram of Tees without a straight run

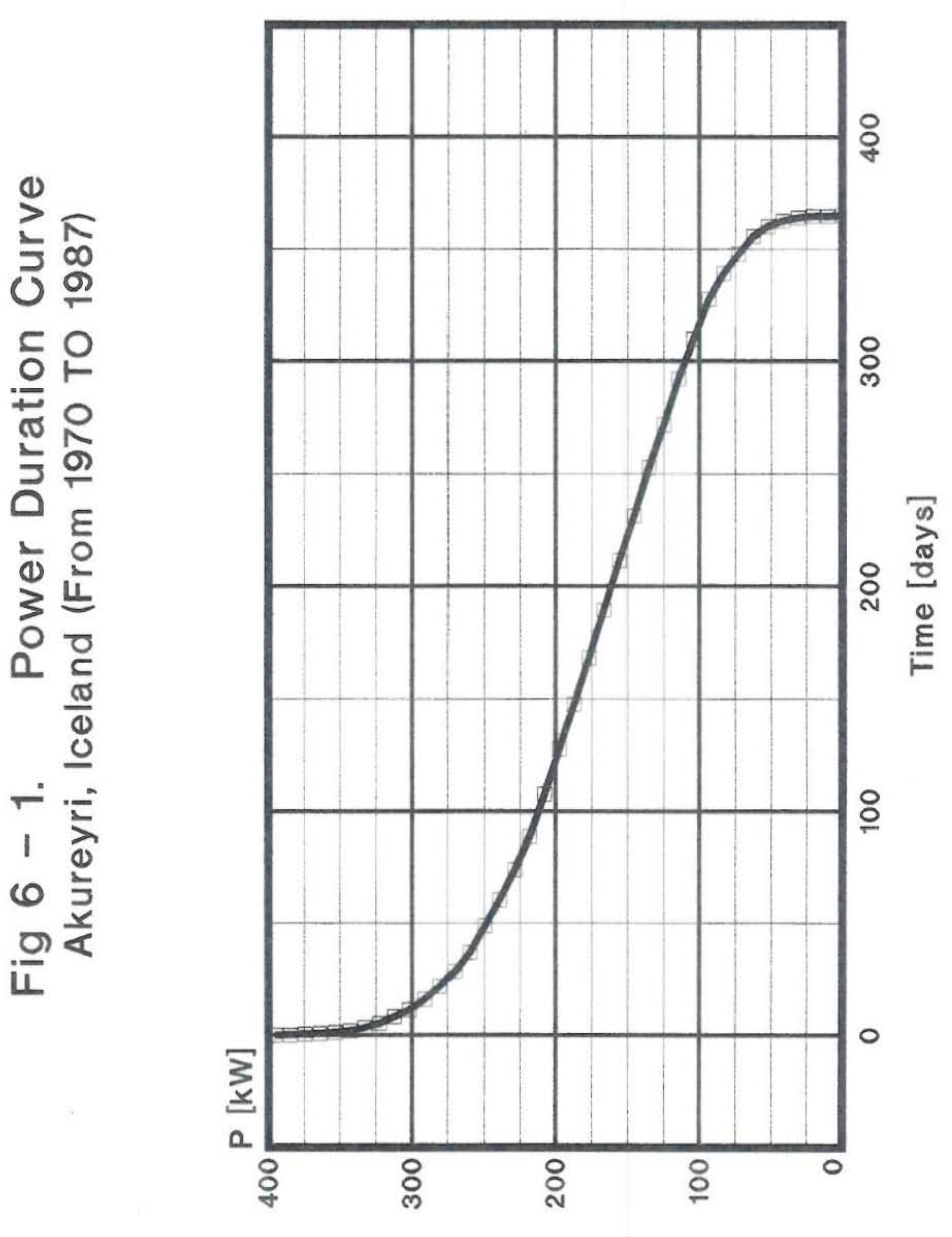

Fig. 6-1 Power Duration Curve
Akureyri, Iceland (from 1970 to 1987)

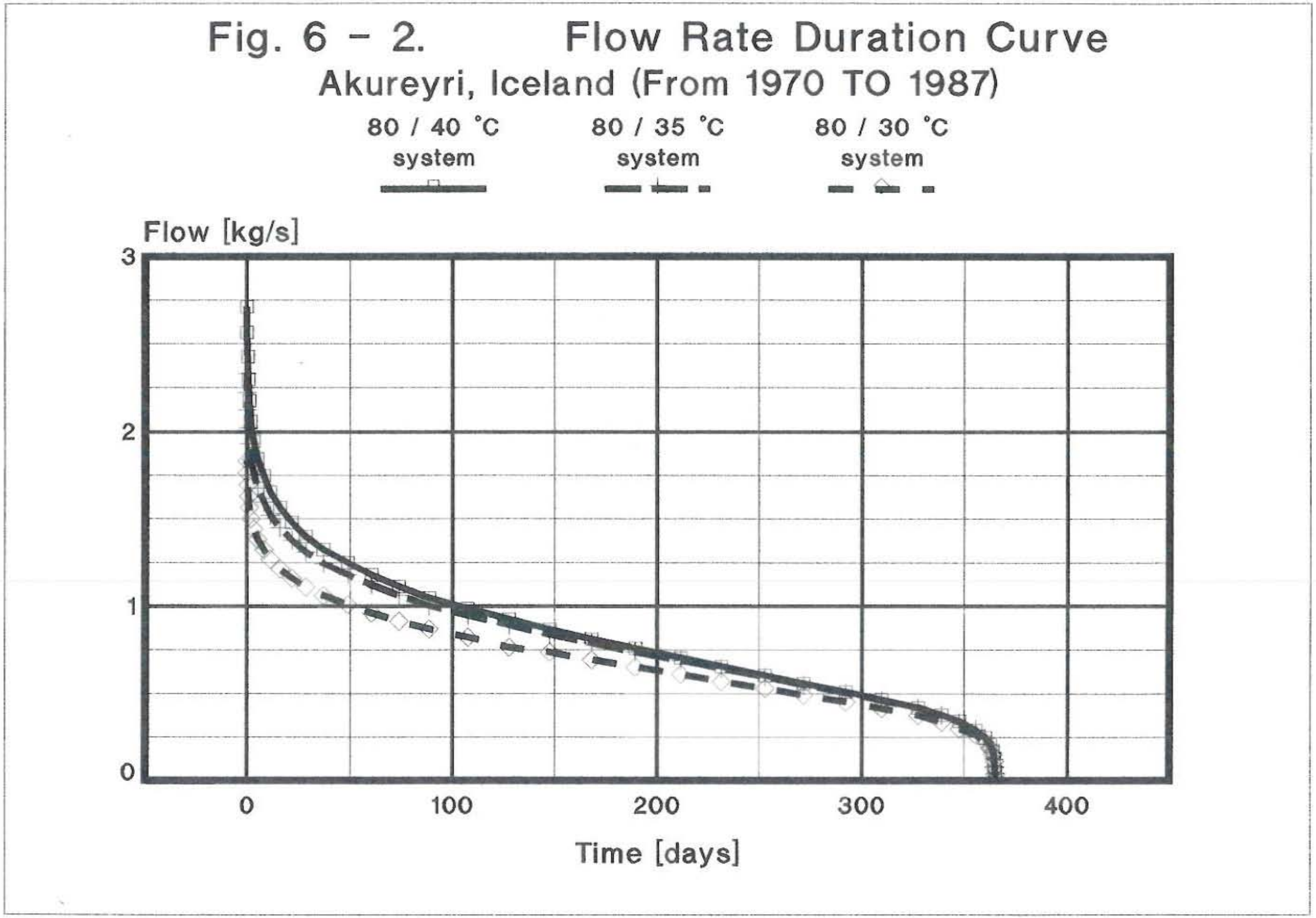

Fig. 6-2 Flow Duration Curve
Akureyri, Iceland (from 1970 to 1987)