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SIMULATION OF GEOTHERMAL DISTRICT HEATING SYSTEMS

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Reykjavík, Iceland
Report 3, 1988

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ABSTRACT

District heating systems are preferable compared to individual heating systems as the heating method is economical, safe and less pollution. Fossil fuels have been used in most of the district heating systems but nowadays geothermal energy is being used in many systems where geothermal energy is available.

Simulation methods enable us to follow behavior of the flow as well as indoor temperature in each building and pressure at every point in the system on hour by hour basis and hereby determine system behavior both during cold waves, and also over long periods of time. In order to use these simulation methods on a district heating system, a fictitious town has been made, and is chosen to be located somewhere in Turkey. The buildings are assumed to be built according to usual Turkish construction methods.

Weather data for this fictitious town is simulated by using temperature variations of the year 1981 in Reykjavik added to the average climate of Denizli, Turkey.

This study is based on the Icelandic method of the design of geothermal district heating systems. However the real weather data from Turkey has been used to evaluate the heat loss of the model building and the heat load of the simulated district heating model network.

CONTENTS

TABLES

FIGURES

INTRODUCTION

The Scope of the Work

A district heating system is defined to be a system where a number of buildings are heated from a central heating plant. Although conventional fuels are frequently used in the heating plant,geothermal energy is increasingly being used in district heating systems in many countries in the world where geothermal energy is available. Many geothermal district heating systems are being operated in the U.S.A., Hungary, the U.S.S.R., France, New Zealand, Italy, Japan and Iceland (Diamant and Kut,1981).

When the temperatures of the geothermal fluids are higher than the minimum supply temperatures in the heating application it is possible to supply all of the heating demands of some group of users (Harrison, 1987).

Determination of the design of the district heating systems depend on calculation of minimum heat load, maximum heat load and estimated annual heat load. During the operation of the district heating systems external heat load and internal heat load are time dependent. To evaluate the changing relationship between internal and external heat loads simulation methods are employed.
This work has been carried out during the UNU Geothermal Training Program as a finally report. The author has been taking a number of lectures on geothermal energy and he has been concentrating on the Reykjavik District Heating System as a special study topic.

There are several methods for calculation of heat load of the buildings and the system design temperature. In this work calculation of the heat loss of the building is based on TS 825 (Turk Standardlari, 1985) and the Karlsson method (Karlsson, 1982).

The main parts of the report as follows:

1. Discussion of theoretical background for district heating simulation.
2. Selection of a typical Turkish building and evaluation of its heat loss.
3. Definition of a fictitious district heating system and creation of suitable weather data.
4. Simulation of the district heating system in fictitious town in Turkey, and study of its response to a cold wave.

The Purpose of the Study

During the operation of the district heating systems, external heat load and internal heat load are time dependent and depend on the weather conditions and operating conditions.

To calculate heat load is very time consuming in large scale district heating system. When planning the connection of premises to a district or group heating network, the heat requirements of the premises must be accurately established. It is necessary to establish the maximum heat demand, the minimum heat demand and overall annual heat demand.

Capital cost is strongly dependent upon physical characteristics of the resource. In a district heating main system the financing of the pipe network is generally the major element in the final cost of heat to the consumer.

Simulation methods enable us to model variations of system variables such as indoor temperature, flow and pressure in the system as a function of weather condition with time for accurate design and operation of district heating systems. Purpose of this study is to use these simulation models to analyze district heating system operation during a cold wave.

THEORETICAL BACKGROUND OF THE DISTRICT HEATING SIMULATION

Introduction

District heating system is designed to be in operation number of years. During the operation years some adjustment are expected as size and type of building and population.

Calculation of estimated energy requirements and fuel consumption of district heating systems are based on many factors. It is necessary to take in to consideration all the variables for accurate design.

Two kinds of methods have been used for the design of district heating system in Iceland. One of them is to calculate heat requirements based on size and type of buildings and other one is to use annual fuel consumption to estimate the heating requirements of the buildings. The first method is known to be very time consuming.

Design Demand Based on Type of Buildings

In this method it is assumed that the power demand of a building depends on size and the heat loss characteristic of buildings. The daily heating requirement of building has been evaluated for the Reykjavik systems.

Over the years for the Reykjavik heating system the maximum average daily heating requirement of buildings connected to the system with direct hot tap water connection:

One story buildings	24.4 W / m^3
Two story buildings	22.1 W / m^3
Three story buildings	19.8 W / m^3
Four story buildings	17.4 W / m^3

Since these figures represent the average daily requirement, the maximum hourly demand is estimated to be 30% higher (Karlsson, 1982).

Design Demand Based on Fuel Consumption

Estimation of annual fuel consumption indicates heat demand in the buildings. Most of the Iceland people enjoy geothermal district heating systems, although the houses outside of the geothermal district heating system are heated with fuel oil and electricity in Iceland.

At the and of 1985, the 29 district heating systems served population of 190,000 people, corresponding to 80% of the Icelanders (Gudmundsson and Palmason, 1987).

Average building volume per person is 117 m^3/person in Iceland (Karlsson, 1982). This analysis is limited for the calculation of annual heat consumption but some information can be obtained.

Weather Conditions

Prediction of energy consumption may be difficult as many variables are involved for a long period. Weather data is important information for prediction of the heat requirements. It is necessary to obtain information on the local climate when the district heating systems are designed. Main parameters are the monthly mean temperature, annual mean temperature and the worst cold wave to expect during the operation time of the system.

It is useful to be able to predict the heating requirement of buildings over a season or even over a year. For this purpose the concept of the degree day is useful, but annual (seasonal) degree days are defined as the number of days out of the year (season) for which the daily mean temperature is below a given temperature multiplied by the difference between the given temperature and the mean temperature for these days, or (Karlsson, 1982).

$$DD(T) = N_T \; (T-T_{mT}) \qquad (1)$$

where

$DD(T)$ = annual degree days, a function of temperature, T,

N_T = the number of days out of the year for which the daily mean temperature is below T,

T_{mT} = the mean temperature for these N_T

For determination of the system design temperature it is necessary to study the available weather data for the area and to estimate the effects of the worst cold waves on the inside temperature of buildings. The cold wave is defined as a period of at least two days for which the outside daily mean temperature is below the system design temperature (Figure,1). The system design temperature must be selected high enough so that the maximum cooling of buildings during the most severe cold wave to be expected will not bring the inside temperature down below a predetermined value. This minimum inside temperature for which district heating systems in Iceland are designed often taken as 17-18 °C (Karlsson, 1982).

Cooling of Buildings During Cold Waves

The steady state rate of heat loss of building is given by the equation

$$Q = K_1 \ (T_i - T_o) \qquad (2)$$

where

Q = heat loss, [W]

K_1= overall heat transfer coefficient of building, [W/°C]

T_i= room temperature, [°C]

T_o= outside air temperature, [°C]

When the heated mass of a building element is m_j and specific heat of the element c_j, the building heat capacity can be expressed as

$$C = \Sigma \ m_j c_j, \qquad (3)$$

When the building is heated with hot water radiators the heat emitted by the radiators is

$$Q = K_r \ (T_r - T_i), \qquad (4)$$

where

K_r = combined heat transfer coefficient for all radiatorsin the building, [W/°C.]

T_r = radiator mean temperature, [°C.]

At the steady state conditions the heat flow from the radiators is equal to the building heat loss. And than this equation is obtained by combining equations 2 and 4 as

$$T_i = K_r T_r \ / \ (K_1 + K_r) + K_1 T_o \ / \ (K_1 + K_r) \qquad (5)$$

$$k_1 = K_1/F_v \ ; \ k_r = K_r/F_v \ ; \ m = C/F_v \qquad (6)$$

where

F_v : gross exterior walls are in the building, m^2.

During the cold wave the outside air temperature, T_o, becomes lower than the system design temperature. This will result in changes of the inside air temperature according to the differential equation can be written as

$$mdT_i/dt = K_r(T_r-T_i)-(K_l(T_i-T_o)$$

or

$$mdT_i/dt + (k_l + k_r)T_i = k_rT_r + k_lT_o, \tag{7}$$

where m, k_l, k_r, and T_r are constants and T_i and T_o are changing with time. Now let

$$T_o = T_g + T_k \ ; \ T_i = (k_rT_r+k_lT_g)/(k_l + k_r) + T, \tag{8}$$

where T_g is the system design temperature. The differential equation (7) is than reduced to the form

$$mdT/dt + (k_l + k_r)T = k_lT_k. \tag{9}$$

By defining the parameters

$$a = (k_l + k_r)/m \tag{10}$$

and

$$b = k_l \ / \ (k_l + k_r) \tag{11}$$

this equation becomes

$$1/a \ dT/dt + T = b \ T_k. \tag{12}$$

a and b will be discussed later. With this substitution T_k is expressing the cold wave, that is how much the outside temperature has gone below the system design temperature. In a similar way, T is than expressing the drop in indoor temperature during the cold wave.

Approximation of Cold Waves

Three basic type of cold waves are defined. These are rectangular cold waves, triangular cold waves and sinusoidal cold waves.

Figure 2 shows that approximation of cold waves. Variation of the indoor temperature can be calculated as follows :

Rectangular Cold Wave

$$T = bT_d\,(1-\exp(-at)), \qquad 0<t<t_o, \tag{13}$$

$$T = bT_d\exp(-at)(\exp(at_o)-1), \; t>t_o \tag{14}$$

where

a and b are defined previously in equations 10, 11,

T_d= minimum temperature or depth of cold wave as measured from the system design temperature,

t_o= length of cold wave.

The minimum inside air temperature is reached at the end of the cold wave, for $t = t_o$.

$$T_{min}= bT_d(1-\exp(-at_o)). \tag{15}$$

Triangular cold wave:

$$T = 2bT_d(at+\exp(-at)-1)/at_o, \qquad 0<t<t_o/2, \tag{16}$$

$$T = 2bT_d(1+a(t_o-T) - \exp(-at)(2\exp(at_o/2)-1))/at_o, \; t_o/2<t<t_o.$$

The minimum inside air temperature is encountered at the time

$$t = \ln(2\exp(at_o/2)-1)/a, \tag{17}$$

and Tmin is,

$$Tmin = 2bT_d(1-\ln(2\exp(at_o/2)-1)/at_o). \tag{18}$$

Sinusoidal Cold Wave

$$T = bT_d \cos(\omega t-\phi)/(1+(\omega/a)^2)^{0.5} , \qquad (19)$$

where

ω is the frequency of the temperature oscillation,

$$\omega = \pi/t_o$$

and

$$\phi = \tan^{-1}(\omega/a). \qquad (20)$$

The minimum temperature is

$$T = bT_d \ / \ (1 + (\ \omega/a)^2)^{0.5} \qquad (21)$$

The cold wave , T_d, is determined in such a way that the degree days for the cold wave measured from the system design temperature, $DD(T_g)$, is equal to the degree days of the approximate cold wave type (Karlsson,1982).

Cold wave type:	Rectangular	Triangular	Sinusoidal
Depth, t_d:	$DD(T_g)/t_o$	$2DD(T_g)/t_o$	π
$DD(T_g)/2t_o$			

If none of the above cold wave approximation seems to fit a given cold wave, the differential equation (9) can be solved by a day basis trough the duration of the cold wave using the daily mean temperature as constant throughout the day. An even better approach would be to use the period between weather observation
(3 hours at most weather station in Iceland) as a basis for the calculations of the cold wave effect on the inside air temperature. Assuming a linear variation of temperature between observations, the solution to (9) is

$$T = T_1 \exp(-at)+b((T_{k1}-T_{ko})t/\Delta_t + (Tk_o-(T_{k1}-T_{ko})/a\Delta t)(1-\exp(-at))), \qquad (22)$$

where

T_1 = inside air temperature at beginning of period,
t = time measured from beginning of period,
Δt = time period between observations,
T_{ko}= outside air temperature at beginning of period,
T_{k1}= outside air temperature at end of period.

If it is assumed that the outside air temperature stays constant,
$T_{k1} = T_{ko}$, between observations, Equation (22) is reduced to the form

$$T = T_1 \exp(-at) + bT_{ko}(1-\exp(-at)). \tag{23}$$

where

T_1 = inside air temperature at the beginning of the period

T_{ko}= outside air temperature at the beginning of the period.

Due to its simplicity, Equation 23 will be used in the subsequent simulation.

Evaluation of the Building Parameters

Evaluation of the building parameters of a model building the being described in (Karlsson, 1982). When the hot water heating systems is operating at conditions other than design conditions, the German Standard DIN 4703 is being used to define heat load for these conditions. According to DIN 4703,

$$Q = Q_o(\Delta T_m/\Delta T_{mo})^{4/3}. \tag{24}$$

The radiator heat load Q_o and the radiator logarithmic mean temperature ΔT_{mo} above the room temperature are at design conditions and Q and ΔT_m are the same quantities at some other conditions. The radiator mean temperature difference is defined as

$$\Delta T_m = (T_f - T_b)/\ln((T_f - T_i)/(T_b - T_i). \qquad (25)$$

where

T_f = inflow water temperature to radiators,
T_b = return water temperature from radiator
T_i = room temperature.

The radiator heat transmission coefficients are assumed to vary with the load, according to the equation

$$k_r/k_{ro} = (\Delta T_m\ /\Delta T_{mo})^{1/3} \qquad (26)$$

leads to

$$Q\ /\ Q_o = k_r \Delta T_m / k_{ro} \Delta T_{mo}$$
$$= (\Delta T_m/\Delta T_{mo})^{4/3} \qquad (27)$$

When a district heating system is designed for a system design temperature different from the design temperature for the radiator heating system, the mean temperature differences will also be different from that at design conditions (Karlsson, 1982).
When noting that the relative heat loss from the buildings equal relative radiator heat load.
Equation 27 becomes

$$Q/Q_o = (T_i - T_g)/(T_{io} - T_{go}) = (\Delta T_m/\Delta T_{mo})^{4/3} \qquad (28)$$

where

T_g = system design temperature, °C,
T_{go}= radiator system outside air design temperature (= -15 °C).

During the operation T_b is changing with time depending on outside temperature. Calculation of T_b is being done by fixed point iteration using Equation 28, and this equation is rewritten as

$$T_b=T_i+(T_f-T_b)/\exp(((T_f-T_b)/(T_{fo}-T_{bo}))*\ln((T_{fo}-T_{io})/(T_{bo}-T_{io}) *((T_{io}-T_{go})/(T_i-T_g))^{3/4}). \qquad (29)$$

Equation 29 enables us to calculate correct T_b by iteration starting with some initial guess of T_b. Experience has shown that this equation is quite stable an converges quickly.

At the system design temperature, T_g, the heat balance for the building gives

$$k_r\Delta T_m = k_l(T_i-T_g) \qquad (30)$$

Two types of building parameters are defined as "b" and "a". Parameter "b" depends only on the k values while parameter "a" depends on building heat capacity as well (Table 1). Equations 10, 11 show the values of "a" and "b" from then is found to be

$$b = k_l \ (k_l+k_r) = \Delta T_m/(\Delta Tm+T_i-T_g), \qquad (31)$$

$$a = k_l \ / \ m \ b \ [1/s]$$

$$a = k_l \ / \ m \ b \ [1/s] * 3600 \ [s/h] * 24 \ [h/day \ ]$$

$$a = k_l \ / \ m \ b \ [1/day] \qquad (32)$$

m is the building heat capacity defined in Equation 3 as

$$m = C/F_v \qquad (33)$$

normalized on basis of the outside wall area (Table 1).

As an example of these calculations, the most common one family building in Iceland is used. This building is one story, about 109 m^2 ground floor area and made of reinforced concrete with 100 mm polyethylene insulation on inside of the walls. For heat losses from the buildings, the heat transfer coefficients specifies the following maximum values of heat transfer coefficients (k values):

	k-value $W/m^2\ °C$		k-value $W/m^2\ °C$
Exterior walls	0.55	Windows	3.2
Roof or ceiling	0.30	Doors on ext.walls	2.5
Floor	0.30	Air change, 0.8/h	0.29 $W/m^3 °C$

The mass of interior walls and floors are based on a mass density of $2.5 * 10^3$ kg/m^3 for poured concrete and $1.5 * 10^3$ kg/m^3 for light aggregate walls. The specific heat for both poured concrete and light aggregate is assumed to be c = 0.88 kJ/kg°C
(Karlsson, 1982).

At the usual Icelandic radiator design condition 80/40, -15 °C,
these values are obtained as,

	T_g	-6	-8	-10	-12	-15
T_{fo} = 80 °C	T_b	31.2	33.1	34.9	36.9	40
T_{bo} = 40 °C	ΔT_m	29.1	30.8	32.4	34	36.4
T_f = 75 °C	b	0.558	0.524	0.519	0.515	0.51

T_{io}= 20 °C T_{go}= -15 °C T_i = 20 °C

where
T_{fo} : inflow water temperature to radiators at radiator design condition,
T_{bo} : return water temperature from radiator at design condition, T_f : inflow water temperature to radiators,
T_{io} : inside room temperature at radiator design condition.
T_{go} : radiator system outside air design temperature.

At the room temperature of 20 °C for the average Icelandic one family house the following values are obtained (Table 1).

$$m = \Sigma m_i = 397.28 \ \mathrm{kJ/m^2 \cdot C},$$

$$a = 0.2175(k_l + k_r) = 0.2175 \ k_l/b \ \mathrm{days}^{-1}. \qquad (34)$$

$$k_l = 2.3522 + 2.9786/(20 - T_g) \quad \mathrm{W/m^2 \cdot C}, \qquad (35)$$

HEAT LOSS CALCULATION FOR THE MODEL BUILDING

Introduction

The model building is typical turkish building selected for calculating the heat losses. Available data for calculating the heat loss is obtained from TS 825 (Turk Standardlari, 1985). According to TS 825, Turkey is divided into three climate zones (Figure, 3). It is required to use different "k" values for calculating the heat loss in the buildings for each zone in Turkey.

The district heating system to be simulated is assumed to be in the first zone. The reason is that geothermal resources are more frequent in the first zone than the other zones.

This study is made at a hypothetical district heating system. Data is very limited for the evaluation of heat losses from the buildings but TS 825 is used.

Description of the Model Building

Most of the Turkish families live in blocks of flats within the first zone. Mainly these blocks of flats are four story. The selected model building is four story, and two flats in every story. Figure 4 which is obtained from TS 825 shows the plan of flat. This building is about 144 m^2 ground floor area, same roof area. The construction of the model building consist of reinforced concrete frame, with columns, beams and slabs. Both the inside and outside finish is of plaster.

The ground floor looses heat to the soil and the top floor looses heat to unheated space under the roof, which is made of wooden framework and is covered with tiles.

Inside air temperature is assumed 20 °C and outside temperature is evaluated as -1 °C. Evaluation of the system design temperature will be discussed in next chapter.

Heat Loss Calculation Based on TS 825

Through the Exterior Walls

If outdoor temperature is lower than the inside temperature, heat loss is calculated by this equation according to TS 825.

$$Q = A*Z*q \tag{36}$$

where

Q : specific heat loss, [W]
A : heat transfer surface area, [m^2]
Z : heating time, [hour]
q : heat loss, [W/m^2]

q is defined by this equation

$$q = k*(t_{ih}-t_{dh}) \tag{37}$$

where

k : heat transfer coefficient, [$W/m^2 \cdot C$]
t_{ih}: inside air temperature, [°C]
tdh: average outdoor temperature, [°C].

t_{ih} = 20°C and t_{dh}= -1°C are assumed.
k is defined by this equation

$$k = 1/(1/\alpha_i+1/\Lambda+1/\alpha_d) \tag{38}$$

where

$1/\alpha_i$: interior surface thermal resistance, [$m^2 \cdot C/W$]
$1/\alpha_d$: exterior surface thermal resistance, [$m^2 \cdot C/W$]
$1/\Lambda$: thermal resistance of the building material, [$m^2 \cdot C/W$]

The usual outside wall is composed of two layers of plaster, 2 cm thick on the outside and 19 cm thick brick as main wall material.
Conductivity is assumed to be 0.87 W/m°C for the plaster and 0.45 W/m°C for the brick. This results in

$$1/\alpha_i = 0.14$$
$$1/\alpha_d = 0.05$$

$$1/\Lambda = d_1/\lambda_{h1} + d_2/\lambda_{h2} + d_3/\lambda_{h3} \quad (39)$$

where

d_1=0.02 m thickness of the interior plaster of wall,
λ_{h1} = 0.87 W/m°C thermal conductivity of plaster,
d^2 = 0.19 m thickness of the brick,
λ_{h2} = 0.45 W/m°C,
d_3 = 0.025 m thickness of the plaster of the exterior wall,
λ_{h3}= 0.87 W/m°C,

this results in

k = 1.57 W/m^2°C for exterior walls.
Exterior net wall area is found to be for the model building

A = 317.04 m^2
and total heat loss through the walls
Q = 10452.8 W.

Through the Doors and Windows

k value is taken from TS 825 (Turk Standardlari, 1985, Table 4) for ordinary doors and single glass windows as 5.2335 W/m^2°C

$$Q = k\ A\ (t_{ih}-t_{dh}) \quad (40)$$

where

t_{ih} = 20 °C

t_{dh} = -1 °C

A = 175.76 m^2

k = 5.2335 W/m^2°C

and Q is to be found

Q = 19316.63 W.

Through the Roof

For calculation of the heat loss to the roof "Λ" value taken from TS 825, Table 3 and roof temperature is assumed as 6 °C.

$$Q = k\,A\,(t_{ih}-t_{dh})$$

$$k = 1/\Lambda + 1/\alpha_i + 1/\alpha_d$$

$1/\Lambda$ = 0.86 m^2 °C / W (TS 825 Table 3)

$1/\alpha_i$ = 0.86 m^2 °C / W (TS 825 Table 5)

$1/\alpha_d$ = 0.1204 m^2 °C / W (TS 825 Table 5)

k = 0.671 W/m^2°C

t_{ih} = 20 °C

t_{dh} = 6 °C

A = 144 m^2

and Q is to be found

Q = 1831.7 W.

Through the Ground Floor

The soil temperature is assumed to be 10 °C.

$$Q = k\,A\,(t_{ih}-t_{dh})$$

$$1/k = 1/\alpha + 1/\Lambda$$

$1/\alpha$ = 0.172 m^2°C/W

(surface heat resistance of the ground),

(TS 825 Table 5)

$1/\Lambda$ = 0,688 m^2°C/W (heat resistance of slab)

(TS 825 Table 3)

$k = 1.16\ W/m^2{\cdot}C$

$A = 144\ m^2$

$Q = 1674.7\ W.$

The result of the calculation:

Total heat loss from the model building = 33275.89 W,
Total volume of the model building = 1584 m^3,
Design demand of the model building = 21 W/m^3

Building Heat Loss Parameters

Most of the hot water heating systems in the first zone are designed with 90 / 70, -6 or 0 °C in Turkey. Two design criteria were assumed for evaluation of building parameters that is 90/70 and 80/40 °C. Design outside temperature of T_o= -7 °C and system design temperature T_g=-1 °C in all cases. So far the model building heat loss has been calculated according to TS 825. In this chapter the model building heat loss is being used to calculate the building parameters.

The characteristic values are obtained for the model building assuming 20 °C room temperature. Table 2 and Table 3 show the results for the first zone at outside temperatures -1 °C and -7°C.

At the design condition, 20 °C room temperature and -1 °C outdoor temperature average building heat load is calculated as 33275.89 W at the model building according to TS 825. By assuming same infiltration heat loss as in the icelandic buildings 0.29 $W/m^3{\cdot}C$, the total infiltration heat loss is calculated as Q_{inf} = 9646 W. This increases the total heat loss to

$$Q_{tot} = 42922.5\ W$$

and design demand of the building to

$$q_{des} = 27\ W/m^3.$$

DESCRIPTION OF THE DISTRICT HEATING MODEL SYSTEM

Introduction

The model system consist of geothermal well as a heat source, well pump, a storage hot water tank, a pumping station, for transportation of the energy, the main transmission pipeline and the energy distribution network.

The model system has been designed as typical part of the Turkish city as the block of flats are concentrated on both side of the street. The trunk branch of the pipeline is in the main street in approximately 2 km distance (Figure 5). The trunk branch is divided into sub branches which are connected the house connection branches. The radiator design conditions for buildings heated with conventional fuels are usually 90/70 °C in Turkey as previously mentioned. This result is what is most common in older buildings, but especially where geothermal heat can be found buildings are now designed with 80/40 °C radiator systems. For this reason some part of the model system has been designed as 90/70°C and the other part is 80/40 °C. The return temperature of the hot water and the hot water demand are evaluated for two parts separately.

Design heat load has been calculated as 27 W/m^3 for the model building. Estimated heat load demand for the system has been calculated based on the design energy demand. Figure 5 shows the city and the distribution system.

Geothermal Wells

Geothermal wells are one of the important items in geothermal district heating systems. The characteristics of the wells and the reservoir performance affect directly the cost of a district heating system.

In this simulation, the well will not be considered, but only the flow from the storage tank to the system.

The Main Transmission Pipeline

Energy is transported from the heat source to the residential region by the main pipeline with length of 2 km. It is assumed that steel pipes are used on the pipeline and all the pipes are insulated with rock-wool. Expansion joints are used for thermal expansion at the horizontal direction. The fixed points are constructed before at every expansion joint for preventing different directional moving of the pipeline.

The Network

The network is assumed to be made from steel tubes isolated with polyurethane. One supply pump pumps water from the storage tank to the system.

Weather Conditions

Real weather data is taken from Virkir, (Virkir 1987), who obtained it originally from the Meteorological Office in Denizli, Turkey. The observation period is 1957-1980, and this has been used in this report for evaluating the system design temperature (Table 4). This Table shows that the minimum outside temperature is -11.4 °C, the maximum outside temperature is 41.3 °C. The minimum average monthly temperature is 5.5 °C while the maximum average monthly temperature is 26.6 °C.

The steady state heat loss calculation of the model building has been done according to outside temperature at -1 °C. In fact of the real weather data shows minimum outside temperature is -11.4 °C. At this condition it is possible to evaluate the system design temperature and the estimated heat loads with DD day of the months. In this report estimation of system design temperature based on the Karlsson method, which evaluates the system design temperature based on variation of indoor temperature during the cold waves lower than the system design temperature.

Equation 23 is defined previously, which defines building cooling during a cold wave, when assuming that the outdoor temperature stays constant between the weather observations. The room temperature is 20 °C at maximum heat load, which is defined to occur at system design temperature.

It is commonly assumed that a minimum indoor temperature of 17-18 °C is acceptable. To obtain realistic weather data for a Turkish town in the first climate zone, available meterological data from Denizli, Turkey was used (Figure 6). As this data contains only average temperatures, temperatures measured at three hour interval in the city of Reykjavik, Iceland during the year of 1981 was considered to describe plausible temperature variations. In order to have the cold wave in January 1981 in Reykjavik to be corresponding to the coldest wave to expect in climate zone 1 in Turkey, these variations are multiplied with 1.5. Follow this

$$T_{aveD} + (T_{oR} - T_{aveR}) * 1.5 = T_{osim} \tag{41}$$

where

T_o : outside temperature

T_{ave} : average temperature

T_{osim}: simulated Denizli outside temperature

Subscript D and R are Denizli and Reykjavik.

Figure 6 shows the simulated weather data together with the linearly interpolated monthly weather data points from design.

Evaluation of the System Design Temperature

Table 4 shows that minimum outside temperature as the number of days with outside temperature under -10 °C or lower is only 0.2, 3.5 days with outside temperature lower than -5 °C and 9 days with temperature lower than -3 °C during the observation periods. At this point the Karlsson method approaches the problem differently by calculating how many degrees the room temperature will be reduced during the cold waves. The minimum room temperature is accepted as 17-18 °C. Equation 23 describes reduction of the room temperature during the cold waves. Equation 23 is

$$T = T_1 \exp(-at) + bT_{ko}(1-\exp(-at)).$$

where

T = drop indoor temperature below 20 °C,
T_1 = inside air temperature at beginning of period,
t = time measured from beginning of the period,
T_{ko} = outside air temperature at beginning of period,
a and b building parameters are defined before.

Figure 7 shows the values of the T and result of the dynamic heat loss calculation for the first days of January. In this calculation it is assumed that outdoor temperature always constant for 3 hours between observation. On the Figure 6 it can be seen that the worst cold wave to expect occurs in the first days of January. This cold wave is so close to the lowest measured temperatures that it can very well be taken to be the worst cold wave to expect during the system operation. When the inside temperature drop is 3.9 °C as allowed, the system design temperature is -1°C and minimum outside temperature is below system design temperature. At this condition heat loss from the model building is 42922.5 W at this system design temperature.

Figure 7 shows the January cold wave and the calculated variation of the indoor temperature.

SIMULATION OF THE MODEL DISTRICT HEATING SYSTEMS

Introduction

So far, theoretical background of the district heating system has been discussed, heat loss calculation of the model building, the building parameters have been calculated for the model building, the system design temperature has been calculated and simulation weather data evaluated for carrying out real data for calculation system design temperature of the model.

The purpose of this chapter is to follow the indoor temperature profile when the system dynamic energy demand is changing with time depending on outside temperature and also to calculate hot water demand.

Description of the Work

Design of Piping Network

In order to be able to perform a simulation, piping network was designed the system shown in Figure 5. Main design criteria was to keep pressure loss between 0.5 and 1.0 bar/km (Karlsson, 1982). Summary of the piping network design is found in Table 5. According to this design system pump was chosen to have characteristic of

$$H = H_o - k\, Q^3. \tag{42}$$

where

- H : pressure head, [m]
- H_o: pressure head at zero floor, [m]
- Q : flow, [m^3/s]
- k : pump constant.

The chosen values are

$$H_o = 120 \text{ [m]},$$
$$k = 3.3 \ 10^5 \text{ [ms/m}^3\text{]}.$$

Schematic of the simulated system is shown in Figure 8.

It is to be noted that all pressure meter output will be in meter of piezometric head.

Simulation of the System

This system description was input to a computer simulation system of the University of Iceland. This program is named SIHEAT and is made available for this project by the University of Iceland-Nordic council district heating research programme.

SIHEAT simulates flow and pressures in the network as well as indoor temperature in each of the buildings. The thermal dynamics of the building are calculated in same way as in Equation 23. The flow restriction through the building radiators which will give indoor temperature of possible 20+/-0.05 °C is than calculated. Minimum flow restriction of the radiator is calculated according to radiator system design temperatures, assuming a required minimum head of 15 m, or

$$k_{1min} = \Delta H_{min}/m_{des} \qquad (43)$$

where

$$\Delta H_{min} = 15 \text{ m}$$
$$m_{des} = Q_{des}/(T_{fo}-T_{bo})c_w.$$

This is considered to correspond to the lack of heat situation, where all radiators valves are fully open. These calculations are repeated until system flows have become stable for every time step.

CONCLUSIONS

The result of the simulation are shown in Figure 9, 10, 11 and 12. Network flows during the January cold wave are shown in Figure 9. Figure 10 shows gage pressures at the points where pressure meters are located. From Figure 10 is can be seen that the farthest and highest points in the system (nodes E and C) have only about 17 m pressure head at maximum load situation. This confirms our pump selection as quite acceptable. It is interesting to note differences in the indoor temperature variations as shown in Figures 11 and 12.

In Figure 11 the indoor temperature variations for the 90/70 °C systems are shown, and they are similar for all buildings, indicating that the distribution network is not a limiting factor in the heating of buildings. On the other hand is substantial variation of the indoor temperature variation of the 80/40 °C systems, indicating that the network is limiting the heat flow to the farthest buildings. Also does this network limitation more than compensate for the better radiator system, the indoor temperature drop is bigger for the 80/40 °C systems than for the 90/70 °C systems.

Despite of this, the simulation shows than actual indoor temperature variation is less then what was anticipated by the calculations of the system design temperature.

The final conclusion is then that the simulation shows that when the pump is selected so that lowest pressure in the system is acceptable (about 17 m head), the indoor temperature drop is considerably less than the maximum acceptable. Therefore the thermal performance of this system is overdesigned when the system is just fulfilling minimum pressure criteria.

ACKNOWLEDGEMENTS

The author wishes to express his special thanks to Mr. Pall Valdimarsson, the author's adviser, and Dr.Jon-Steinar Gudmundsson, the director of UNU Geothermal Training Programme for their invaluable guidance and comments during the training course and the writing of the report. Thanks are also expressed to Prof. Valdimar K. Jónsson, University of Iceland, Dr. Oddur B. Björnsson, Fjarhitun Consulting Engineers Ltd for their valuable advice, information and discussions. The Turkish authorities are thanked for granting leave during the period of the fellowship. Finally the author would like to thank everybody who has presented lectures or given assistance to the author during the whole training programme.

NOMENCLATURE

A : radiator surface area, (m^2)

a $= (k_r + k_l)/m$ building parameter

b : $k_l/(k_r + k_l)$ building parameter

C : heat capacity of items inside a heated building, (kJ/K)

c_j : specific heat of item j inside building, (kJ/kg.K)

c_w : specific heat of water, (kJ/kg.K)

DD(T): annual degree days below temperature (T)

F_v : gross exterior wall area of building, (m^2)

K_l : overall heat transfer coefficient of building, (W/K)

K_r : combined heat transfer coefficient for all radiators in building, (W/K)

k : radiator heat transfer coefficient, k/ $(m^2.K)$

k_l : normalized heat transfer coefficient of building $= K_l/F_v$

k_r : normalized radiator heat transfer coefficient $= K_r/F_v$

L : length of pipe, (m)

m : normalized heat capacity of items inside building $= (C/F_v)$

m_j : mass of item j inside building, (kg)

m : mass water flow rate, (kg/s)

N_T : number of days in year with mean temperature below (T)

Q : heat loss from building or pipe, (W)

T : temperature, (°C)

T_b : return water temperature from radiators, (°C)

T_d : depth of cold wave below system design temperature

T_f : inflow water temperature to radiators, (°C)

T_g : system design temperature, (°C)

T_i : room temperature, (°C)

T_k : $T_o - T$

T^m : annual mean air temperature, (°C)

TmT: mean temperature for N_T days in year, (°C)

T_o : outside air temperature, (°C)

T_r : mean water temperature in radiators, (°C)

ΔT_m: logarithmic mean temperature differences, (°C)

t : time

t_o : duration of cold wave, days

α : surface heat transfer coefficient, ($W/m^2 \cdot C$)

λ : thermal conductivity, (W/m K)

Λ : thermal resistance of building material, ($m^2/W \cdot C$)

η : density, (kg/m^3)

ϕ : phase angle for sinusoidal cold wave = $\tan^{-1}(\omega/a)$

ω : frequency of sinusoidal cold wave = π/t_o

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Table 1 - Characteristic values for an average one story building Icelandic home (Karlsson, 1982).

			k_i $W/m^2 \cdot {}^oC$	m_i $kJ/m^2 \cdot {}^oC$
	Net floor area, m^2	109.55		
	Gross exterior wall area, m^2	127.30		
Normalized Areas m^2/m^2	Windows	0.2185	3.2	
	Doors on exterior walls	0.0609	2.5	
	Net exterior walls	0.7206	0.55	
	Roof (ceiling)	0.9323	0.3	
	Floor (outer section)	0.2704	0.3	
	Floor (inner section)	0.6619	$0.3 \cdot 15/(20-T_g)$	
Normalized Volumes m^3/m^2	House volume	2.5641	0.29	
	Poured concrete partitions	0.0248		54.56
	Light aggregate partitions	0.0703		92.80
	Poured concrete floor	0.1136		249.92

Table 2 - The characteristic values at 20 °C for the model building.

Net floor area, m^2	144
Gross exterior wall area, m^2	492.8

Heat loss parameters	Areas m^2	Normalized Areas m^2/m^2	k_i W/m^2 °C
Windows	175.7	0.356	5.2335
Net exterior walls	317	0.643	1.57
Roof (ceiling)	144	0.136	$1.16*14/(20-T_g)$
Floor	144	0.136	$1.45*10/(20-T_g)$

Heat capacities	Volumes m^3	Normalized Volumes m^3/m^2	m_i Normalized heat capacities kJ/m^2
House volume	1584	0.381	
Poured concrete partitions	14.3	0.029	54.4
Light aggregate partitions	98.28	0.769	254.3
Poured concrete floor	129.9	0.263	491.8

Note : normalized values are normalized on basis of gross exterior wall area.

Table 3 - Evaluation of building parameters for the model building at outside temperature of -7 °C.

T_g	1	-1	-3	-5	-7
T_b	57.37	63.37	68.48	71.93	73.74
ΔT_m	45.63	48.98	51.73	53.52	54.42
b	0.706	0.699	0.692	0.681	0.668
a	0.706	0.639	0.642	0.648	0.657
m	800.4	800.4	800.4	800.4	800.4
k_1	4.18	4.147	4.118	4.093	4.072
Q	39168.5	42922.4	46676.3	50430.2	54184.1

T_f : 75 °C T_{fo} : 90 °C T_{go} : -7 °C
T_i : 20 °C T_{bo} : 70 °C T_{ground}: 10 °C
Tbo : 20 °C T_{roof}: 6 °C

T_g	1	-1	-3	-5	-7
T_b	31.69	34.22	36.89	39.68	42.57
ΔT_m	27.97	30.15	32.28	34.36	36.40
b	0.595	0.589	0.583	0.578	0.574
a	0.758	0.759	0.761	0.763	0.715
m	800.4	800.4	800.4	800.4	800.4
k_1	4.18	4.147	4.118	4.093	4.072
Q	39168.5	42922.4	46676.3	50430.2	54184.1

T_f : 75 °C T_{fo} : 80 °C T_{go} : -7 °C
T_i : 20 °C T_{bo} : 40 °C T_{ground}: 10 °C
T_{bo} : 20 °C T_{roof}: 6 °C

Table 4 - Weather data for Denizli, Turkey (Virkir, 1985).

İSTASYON ADI:DENİZLİ
İSTASYON YÜKSEKLIĞI: 428 M

ENLEM DERECESİ:37 47
BOYLAM DERECESİ:29 05
RASAT SÜRESİ:1957-1980 (24)

METEOROLOJİK ELEMANIN ADI	AYLAR												
	1	2	3	4	5	6	7	8	9	10	11	12	YILLIK
ORTALAMA SICAKLIK	5.5	6.9	9.9	14.1	19.2	23.8	26.6	25.9	21.5	16.3	11.4	7.7	15.7
ORTALAMA SICAKLIĞIN>5.0 OLDUĞU GÜNLER SAYISI	16.8	19.6	27.7	29.9	31.0	30.0	31.0	31.0	30.0	31.0	28.2	21.8	327.8
ORTALAMA SICAKLIĞIN>10.0 OLDUĞU GÜNLER SAYISI	4.3	6.2	15.8	25.8	30.9	30.0	31.0	31.0	30.0	29.9	21.0	7.9	263.7
EN YÜKSEK SICAKLIK	22.6	23.8	29.0	35.2	37.0	39.2	41.3	41.2	37.0	33.5	29.9	26.6	41.3
EN YÜKSEK SICAKLIĞIN TARİHİ	3.71	14.78	31.77	12.70	30.80	24.73	20.73	25.58	17.72	17.60	3.59	21.63	20. 7.73
EN YÜKSEK SICAKLIĞIN>30.0 OLDUĞU GÜNLER SAYISI	0.0	0.0	0.0	0.6	5.4	18.5	28.1	27.8	13.0	1.9	0.0	0.0	95.2
EN YÜKSEK SICAKLIĞIN>25.0 OLDUĞU GÜNLER SAYISI	0.0	0.0	0.4	5.3	18.4	27.5	30.8	30.9	26.3	12.5	0.6	0.0	152.7
EN YÜKSEK SICAKLIĞIN<0 OLDUĞU GÜNLER SAYISI	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
EN DÜŞÜK SICAKLIK	-10.5	-11.4	-5.0	-1.7	2.7	9.0	12.6	11.6	6.6	-0.8	-4.5	-10.4	-11.4
EN DÜŞÜK SICAKLIĞIN TARİHİ	19.64	9.65	1.61	12.69	14.80	9.62	4.64	2.68	30.70	8.71	27.67	23.67	9. 2.65
EN DÜŞÜK SICAKLIĞIN<0 OLDUĞU GÜNLER SAYISI	10.5	6.9	3.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.6	5.5	28.0
EN DÜŞÜK SICAKLIĞIN<-1.0 OLDUĞU GÜNLER SAYISI	8.6	5.6	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0	21.4
EN DÜŞÜK SICAKLIĞIN<-2.0 OLDUĞU GÜNLER SAYISI	6.1	4.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.3	14.3
EN DÜŞÜK SICAKLIĞIN<-3.0 OLDUĞU GÜNLER SAYISI	4.1	3.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	9.0
EN DÜŞÜK SICAKLIĞIN<-4.0 OLDUĞU GÜNLER SAYISI	2.8	1.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	5.4
EN DÜŞÜK SICAKLIĞIN<-5.0 OLDUĞU GÜNLER SAYISI	2.0	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.5
EN DÜŞÜK SICAKLIĞIN<-10.0 OLDUĞU GÜNLER SAYISI	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
EN DÜŞÜK SICAKLIĞIN>10.0 OLDUĞU GÜNLER SAYISI	0.6	0.8	2.3	8.8	25.3	29.9	31.0	31.0	28.7	18.9	6.0	2.2	185.5
EN DÜŞÜK SICAKLIĞIN>20.0 OLDUĞU GÜNLER SAYISI	0.0	0.0	0.0	0.0	0.1	2.0	9.3	6.1	0.3	0.0	0.0	0.0	17.8

Note :" AYLAR" means "months"

" ORTALAMA SICAKLIK" means "average temperature"

" EN YUKSEK SICAKLIK" means "minimum temperature"

" EN DUSUK SICAKLIK" means "minimum temperature"

Table 5 - Summary of the Pipe System design.

Pipe run	House volume m3	Sum demand W	Sum flow l/s	Pipe diam. mm	Vel. m/s	Pipe length m	Reynolds number	Pressure drop mVs	Pressure drop bar/km
G1-G	3500	94500	0.49	35.9	0.48	320	36337.6	2.990	0.934
G2-G	6000	162000	0.84	53.0	0.38	170	42194.7	0.761	0.448
G-F	13000	351000	1.82	68.8	0.49	300	70426.7	1.443	0.481
F1-F	8000	216000	1.12	52.5	0.52	250	56795.4	2.085	0.834
F-E	28000	756000	3.93	77.9	0.82	300	133968.6	3.33.	1.110
E1-E	3500	94500	0.49	35.9	0.48	320	36337.6	2.883	0.901
E-D	6000	972000	5.05	102.3	0.61	600	131162.4	2.931	0.489
D-C	65000	1755000	9.11	105.3	1.05	300	230073.9	2.371	0.593
J1-J	6000	162000	4.84	102.3	0.59	275	166770.2	1.661	0.604
J-K	8700	234900	7.01	105.3	0.81	450	234927.4	4.239	0.942
K1-K	3500	94500	2.82	68.8	0.76	120	144651.3	1.281	1.067
K-C	16500	445500	13.30	130.0	1.00	350	360897.0	3.446	0.985
C-B	82500	2227500	22.42	155.4	1.18	2000	383452.8	18.327	0.916

Note: values between G1-G and D-C represent new design of the pipe system at 80/40 °C, while J1-J represent a existing design at 90/70 °C.

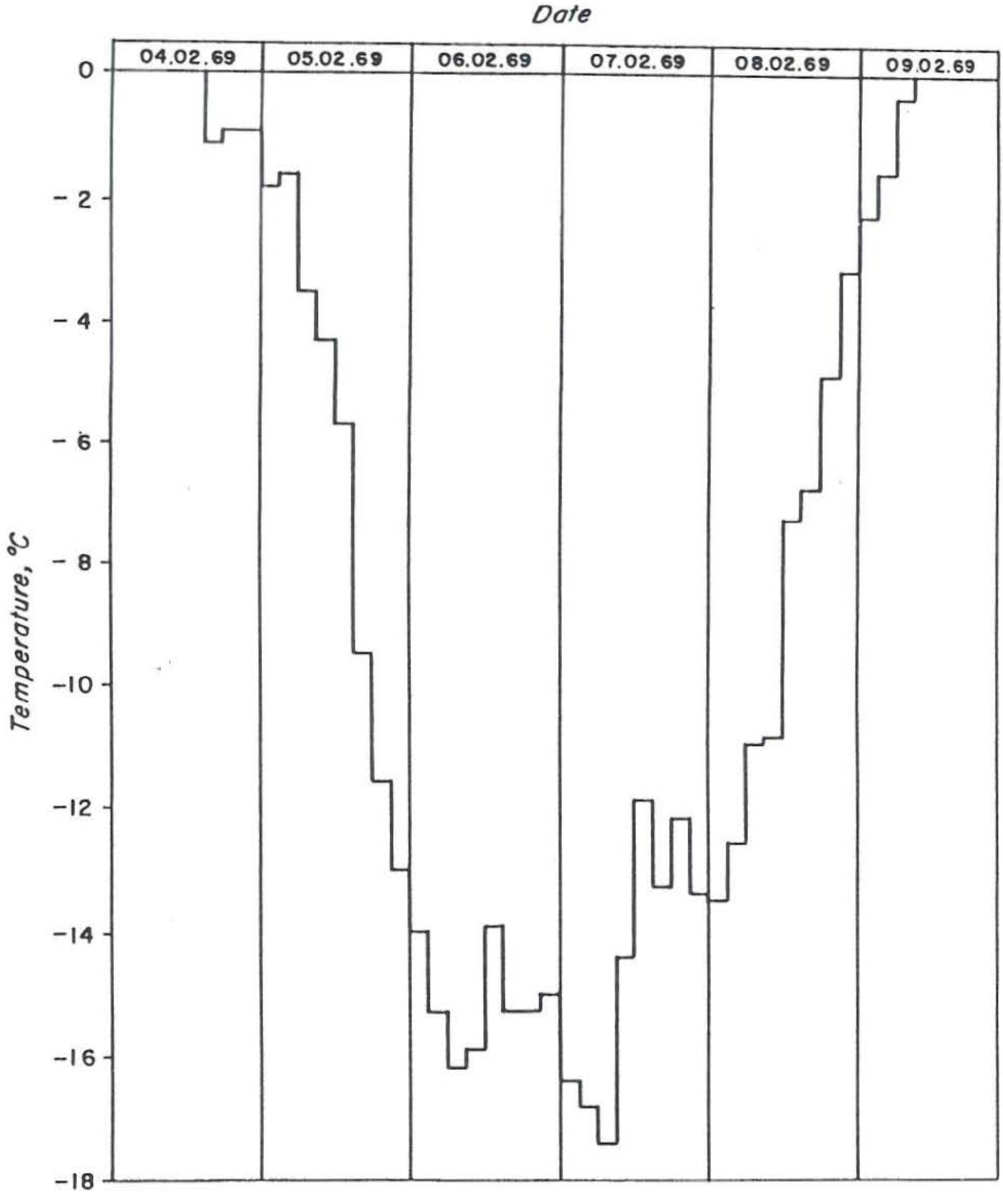


Figure 1 - Observed temperatures in Reykjavik during a severe cold wave (Karlsson, 1982).

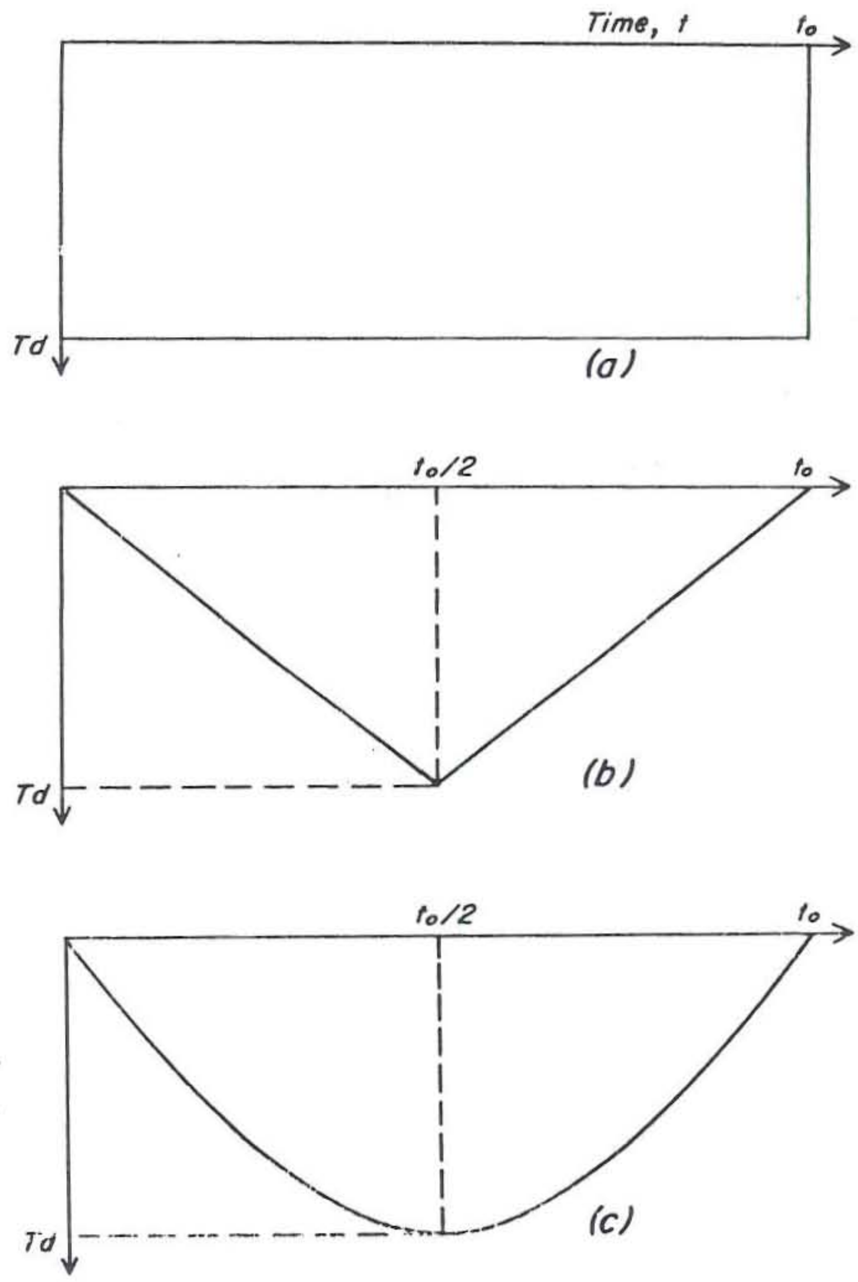
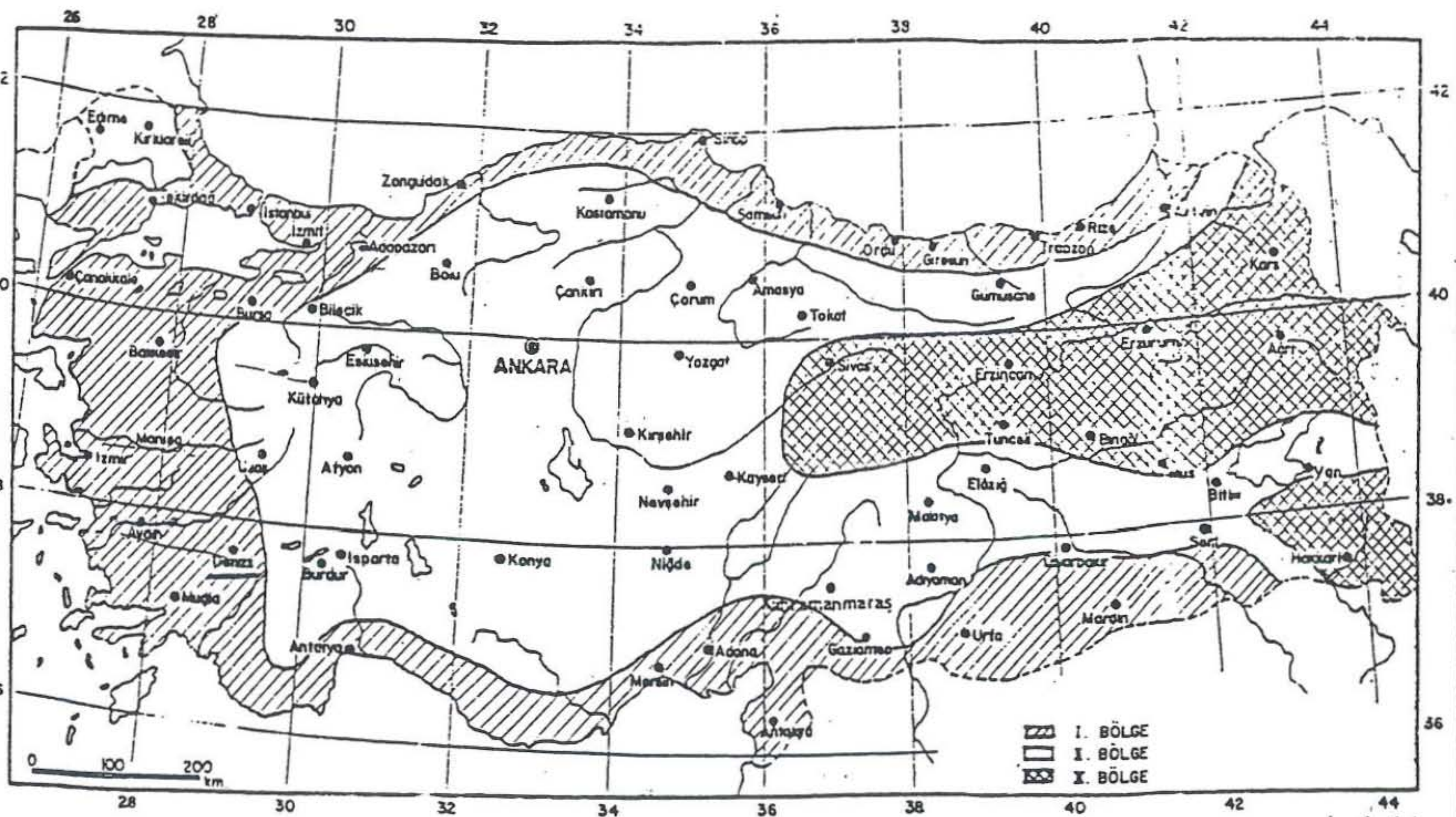


Figure 2 - Cold wave approximations (Karlsson, 1982).



HARİTADA I. BÖLGE İÇİNDE OLUPDA RAKIMI 1000 M.NİN ÜSTÜNDE OLAN YERLER, II. BÖLGEDE, HARİTADA II. BÖLGE İÇİNDE OLUPTA RAKIMI 1500 M.NİN ÜSTÜNDE OLANYERLER III. BÖLGE İÇİNDE KABUL EDİLİRLER. III, BÖLGEDE OLUP RAKIMI 1000 M.NİN ALTINDA OLAN YERLER I. BÖLGEDE; II. BÖLGEDE OLUP RAKIMI 600 M.NİN ALTINDA OLAN YERLER I. BÖLGEDE KABUL EDİLİRLER.

ŞEKİL_ I ISI ETKİLERİNDEN KORUNMA YÖNÜNDEN TÜRKİYE İKLİM BÖLGELERİ HARITASI

Figure 3 - Climate zones in Turkey (Virkir, 1985).

Note : "BÖLGE" means "zone".

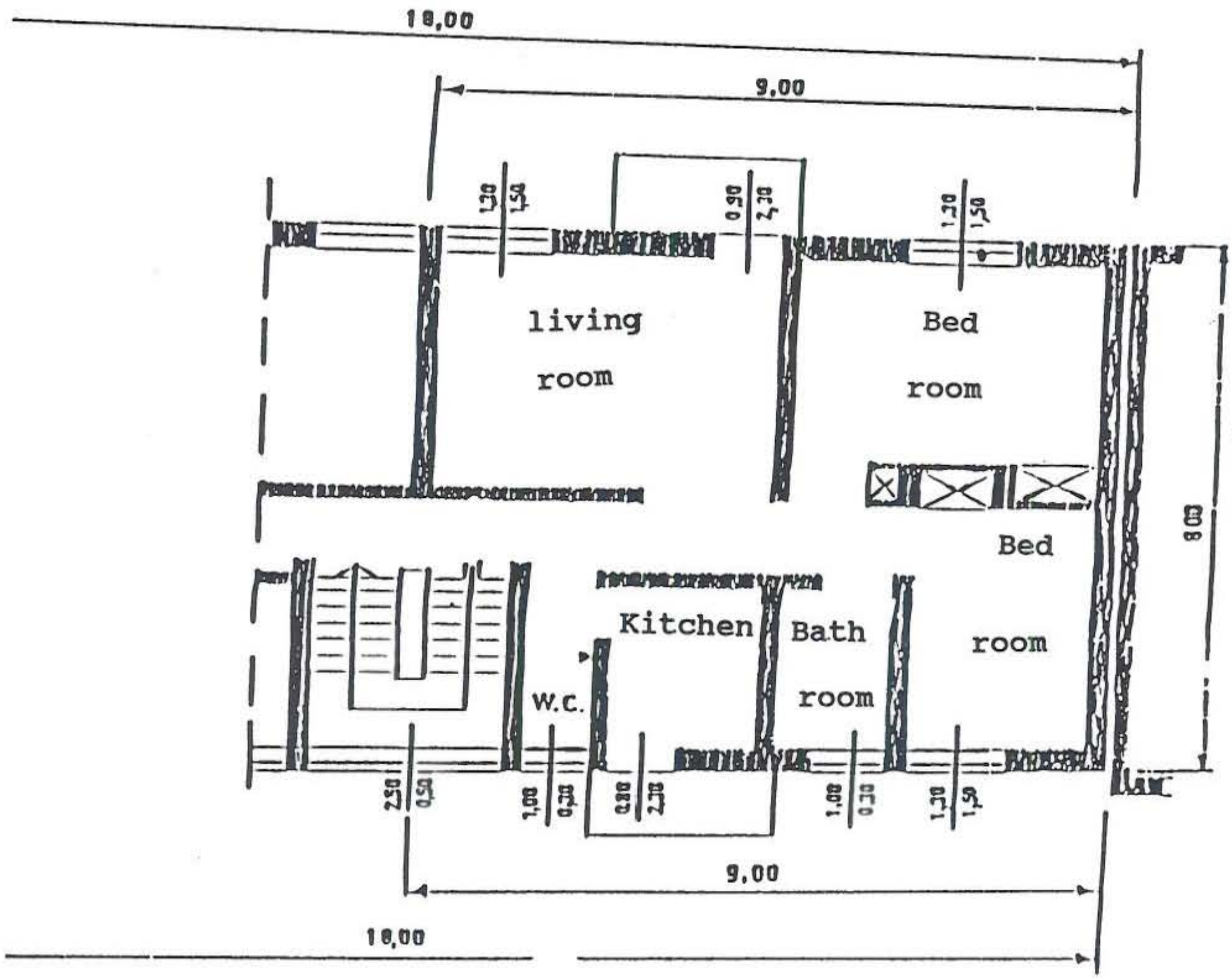
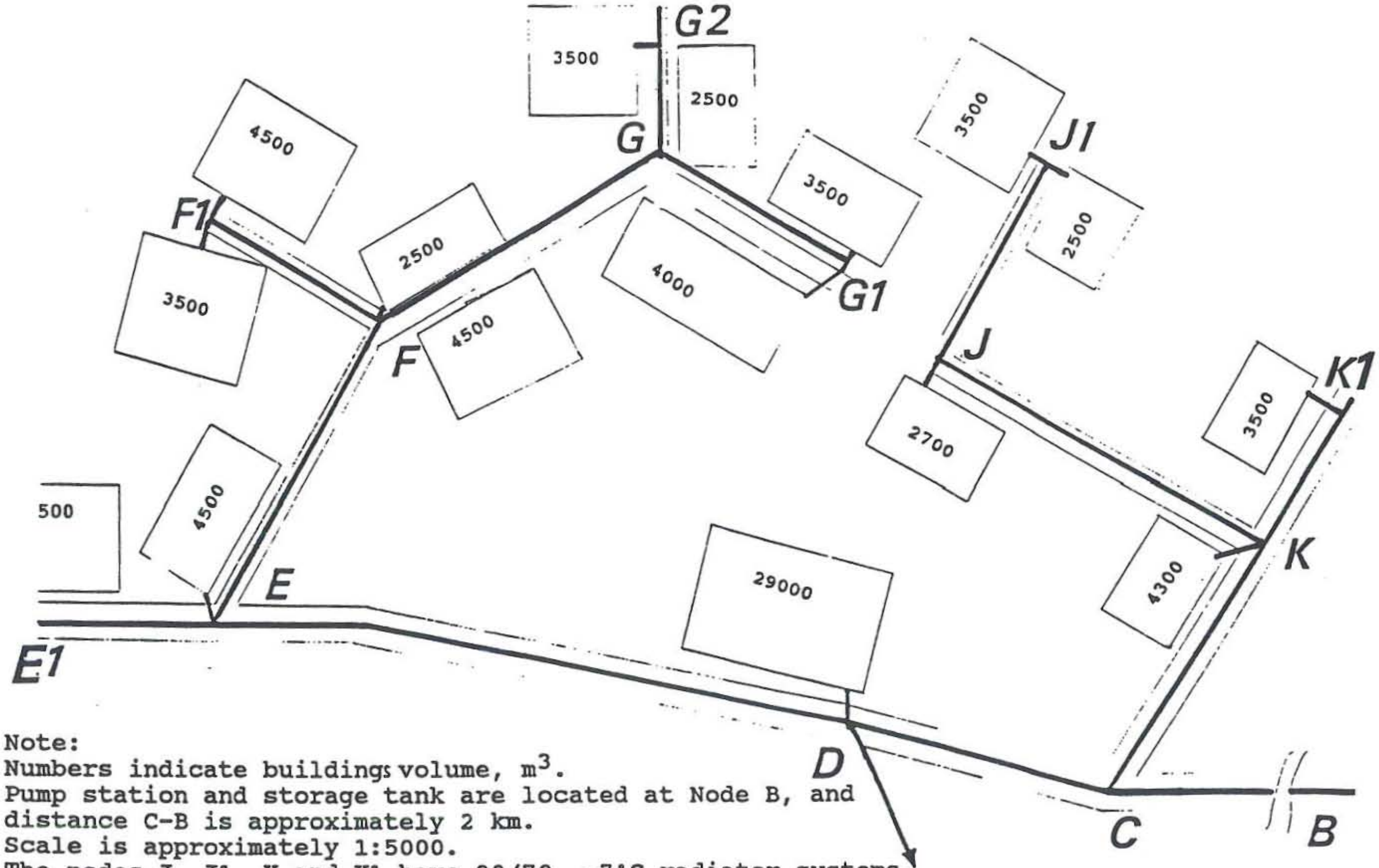


Figure 4 - Plan of the model building layout
(Türk Standardları, 1985).



Note:
Numbers indicate buildings volume, m^3.
Pump station and storage tank are located at Node B, and distance C-B is approximately 2 km.
Scale is approximately 1:5000.
The nodes J, J1, K and K1 have 90/70, -7°C radiator systems.
The others have 80/40, -7°C systems.
A future connection is assumed in Node D about $20*10^3$ m^3, 2.8 l/s flow.

Figure 5 - Layout of the model system.

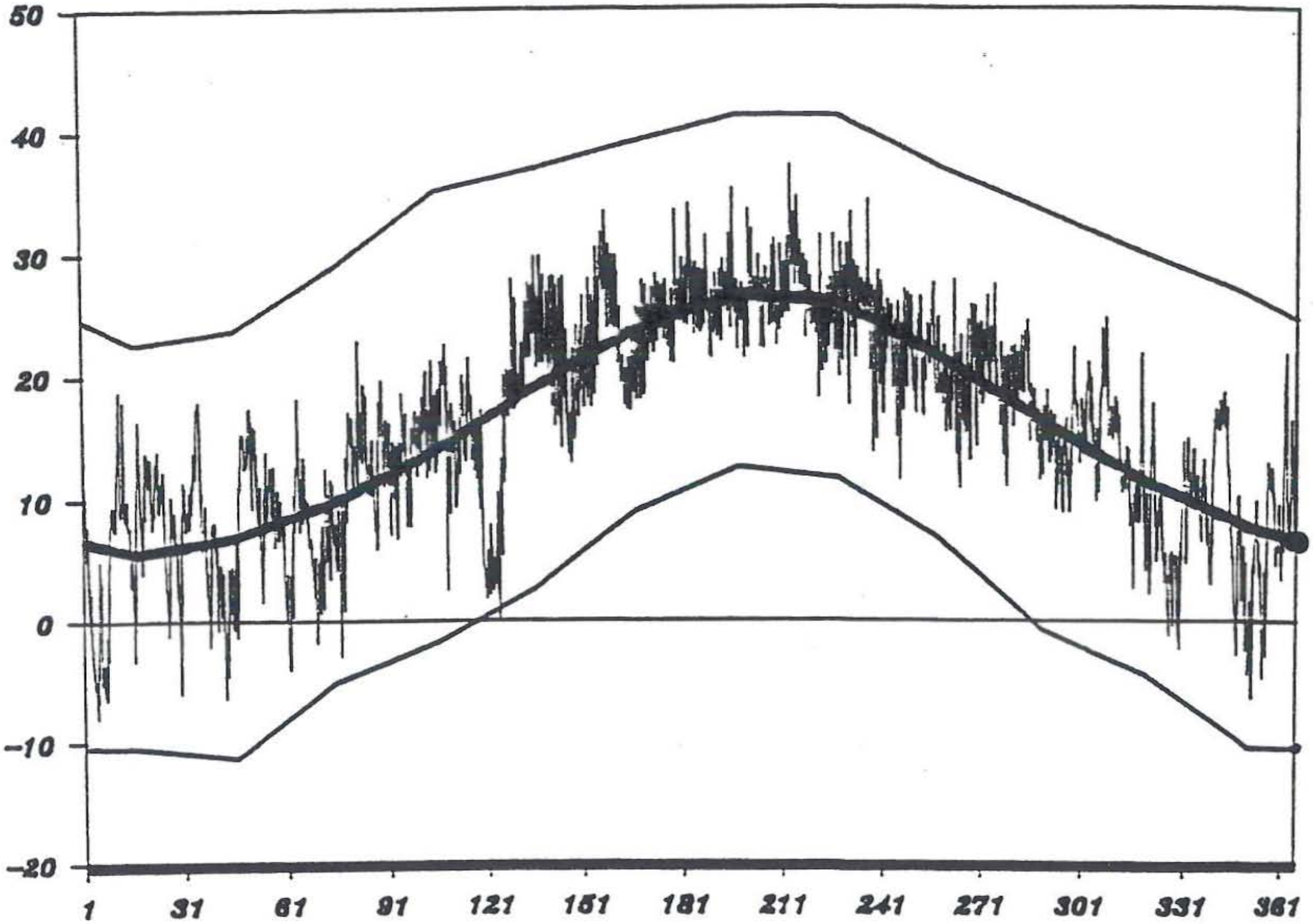


Figure 6 - Weather data-actual maximum, minimum, average values for Denizli Turkey together with simulated temperature.

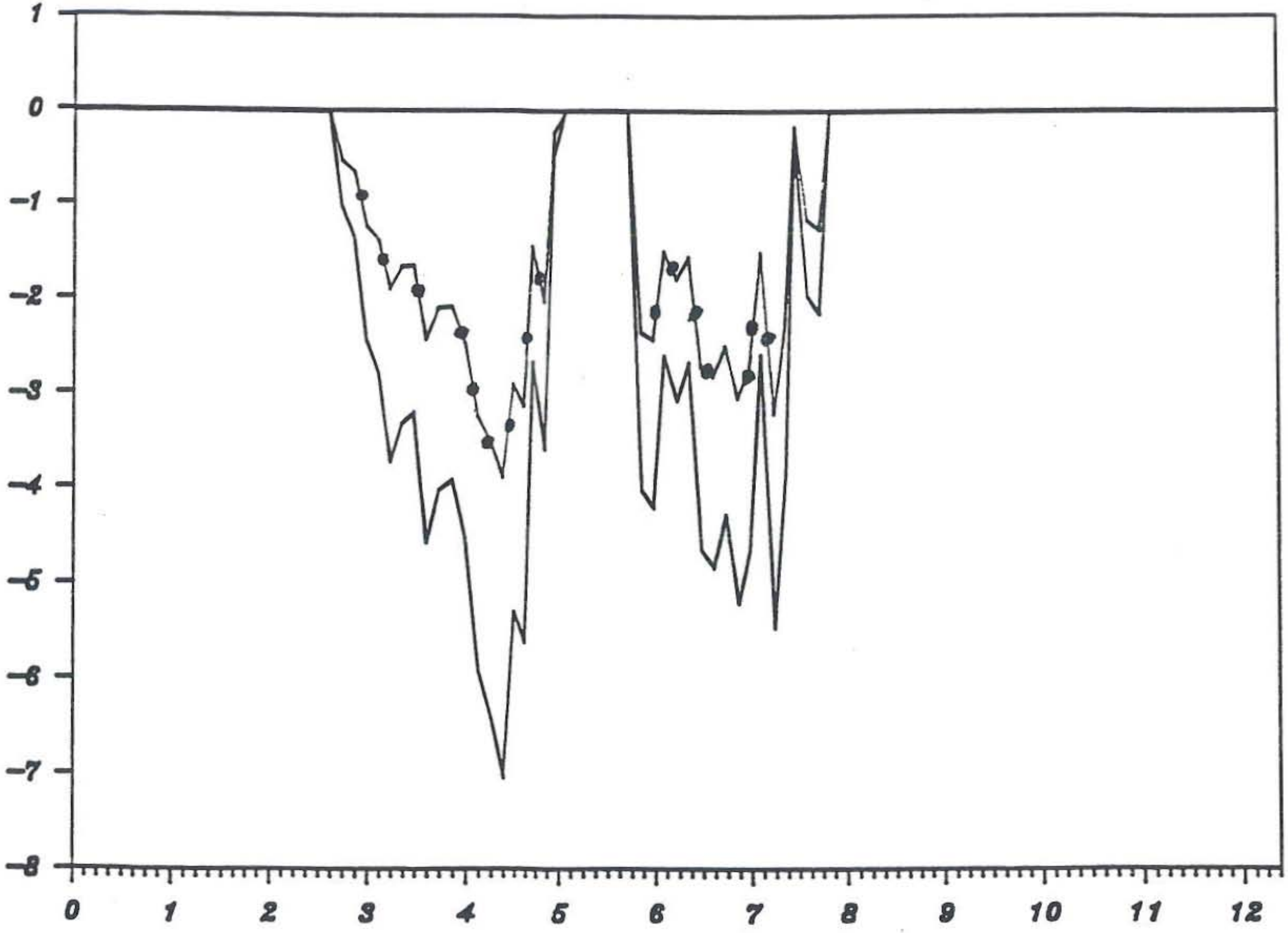


Figure 7 - Temperature variation during a cold wave.

—— outside temperature below system design temperature,

—●— drop of indoor temperature.

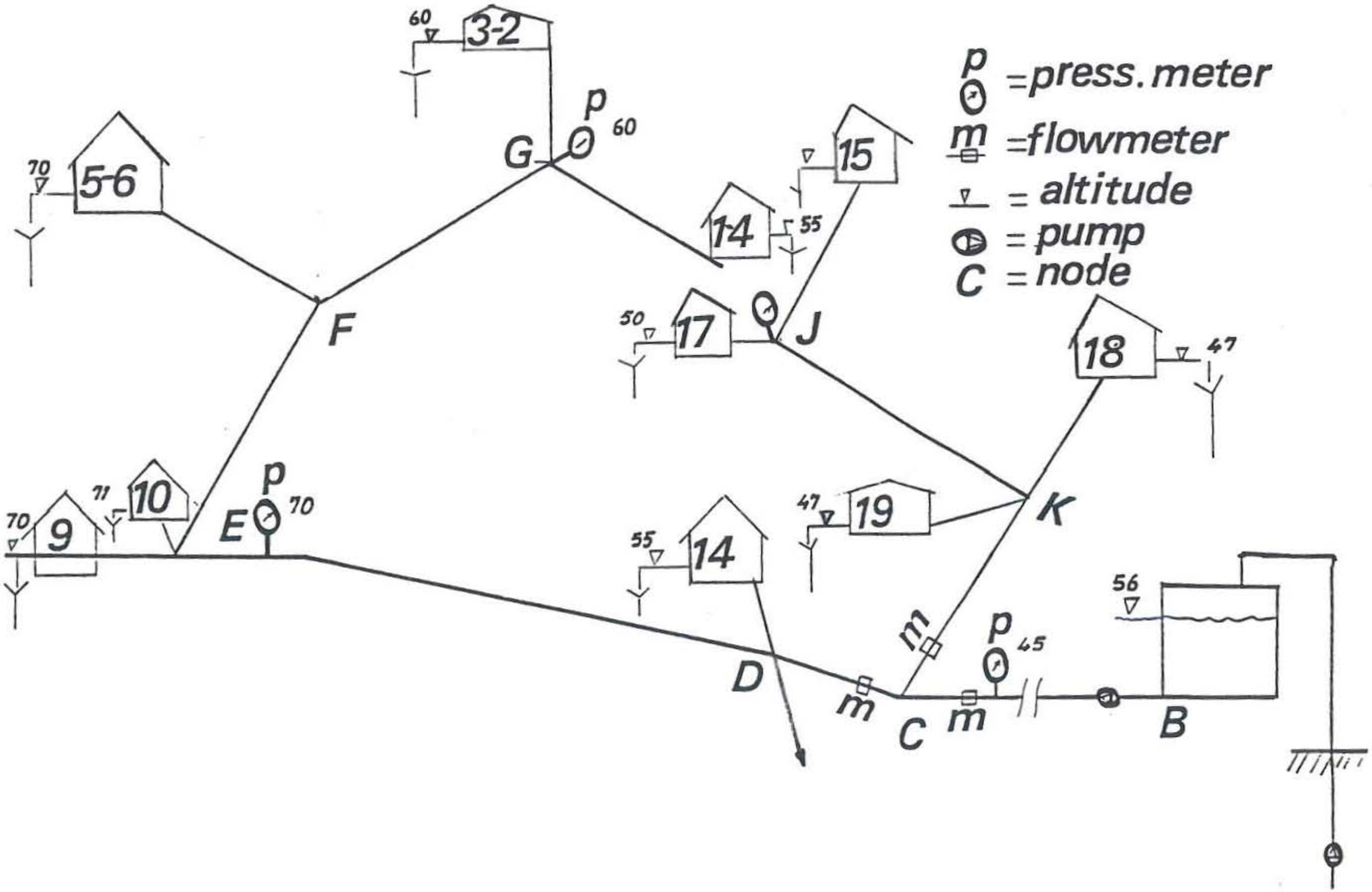


Figure 8 - Shematic of the simulated model system.

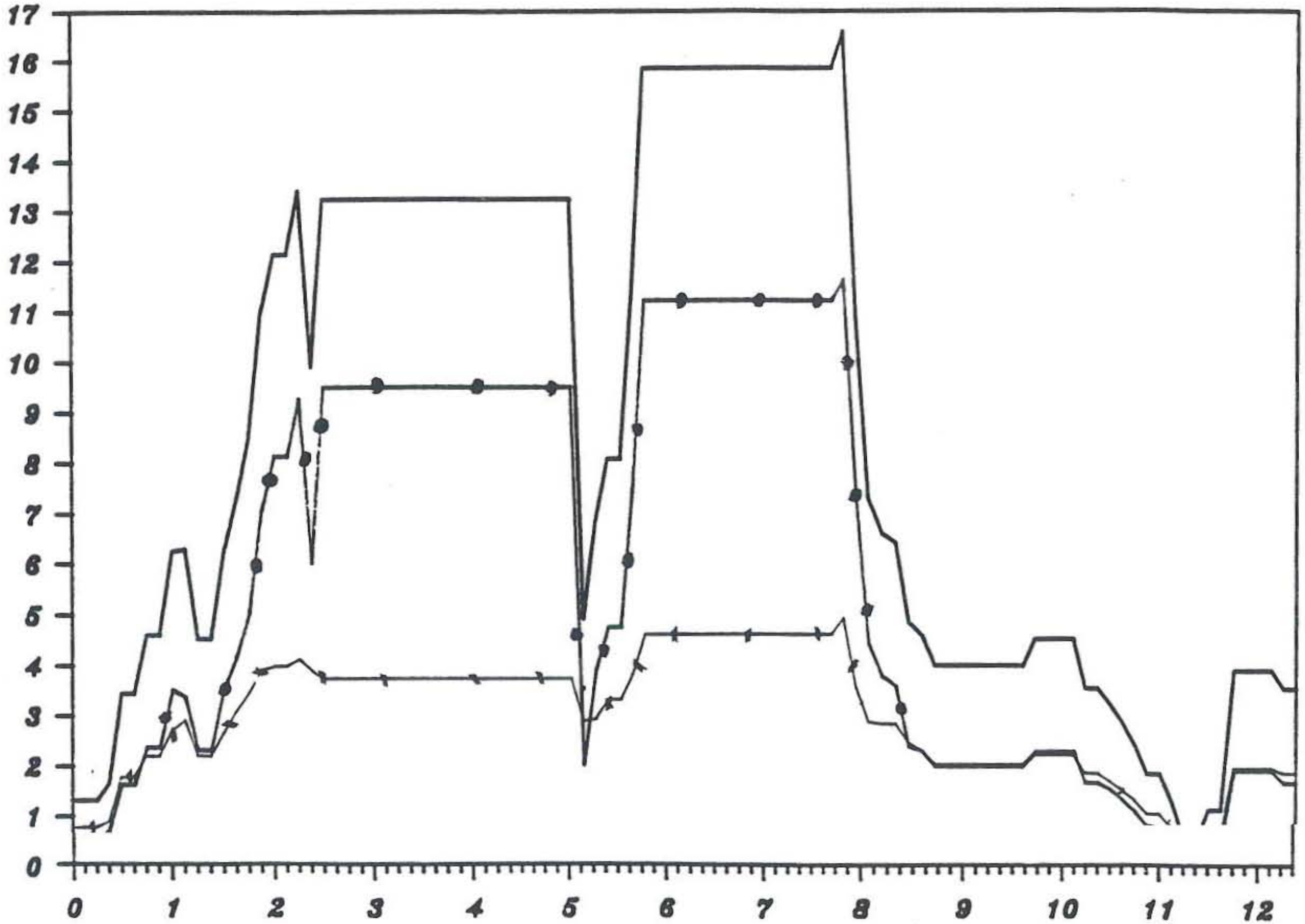


Figure 9 - System mass flows.

——— massflow in pipe C-B,

—◆— massflow in pipe C-K for 90/70 systems,

—•— massflow in pipe C-D for 80/40 systems.

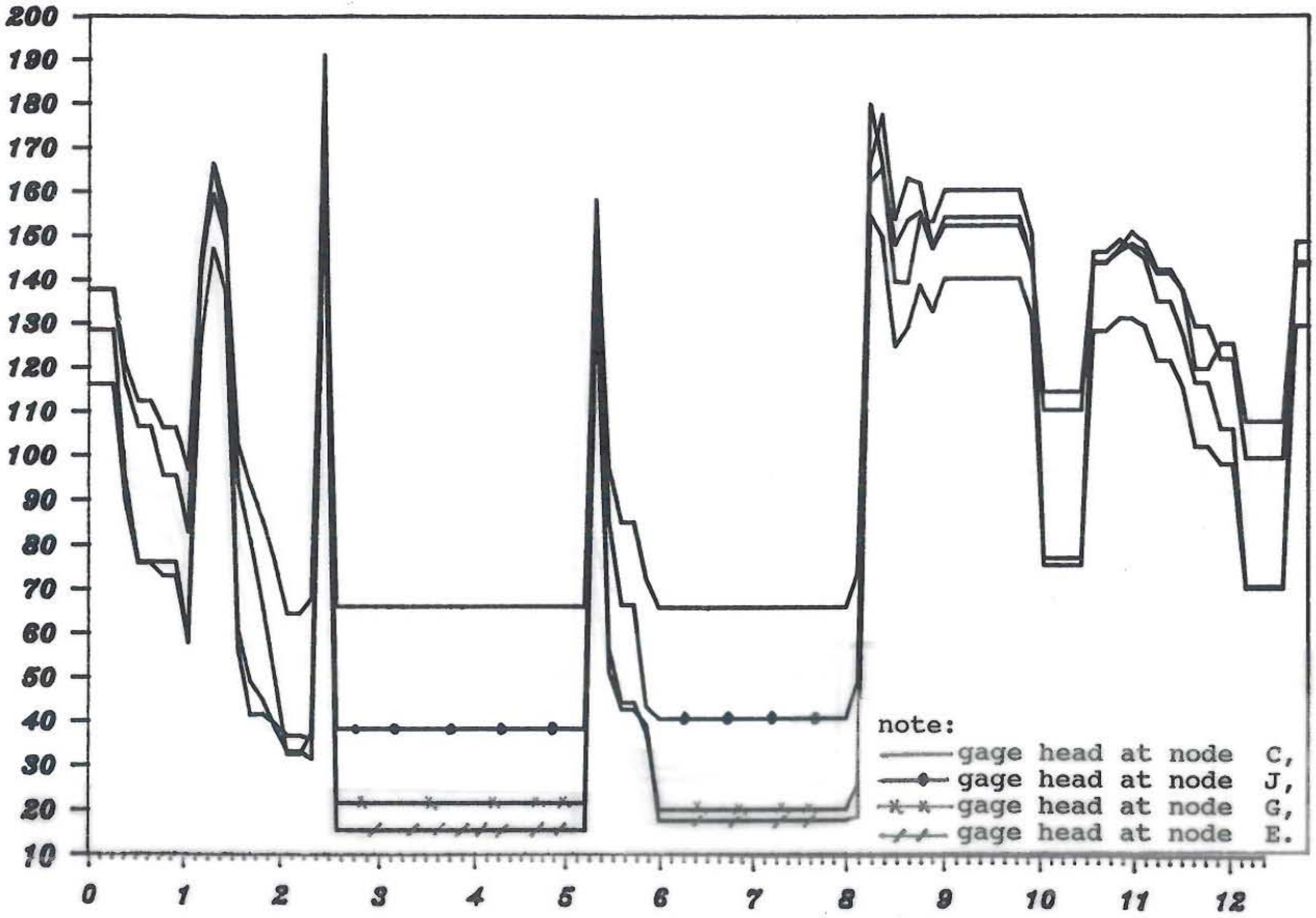


Figure 10 - Simulated system pressures.

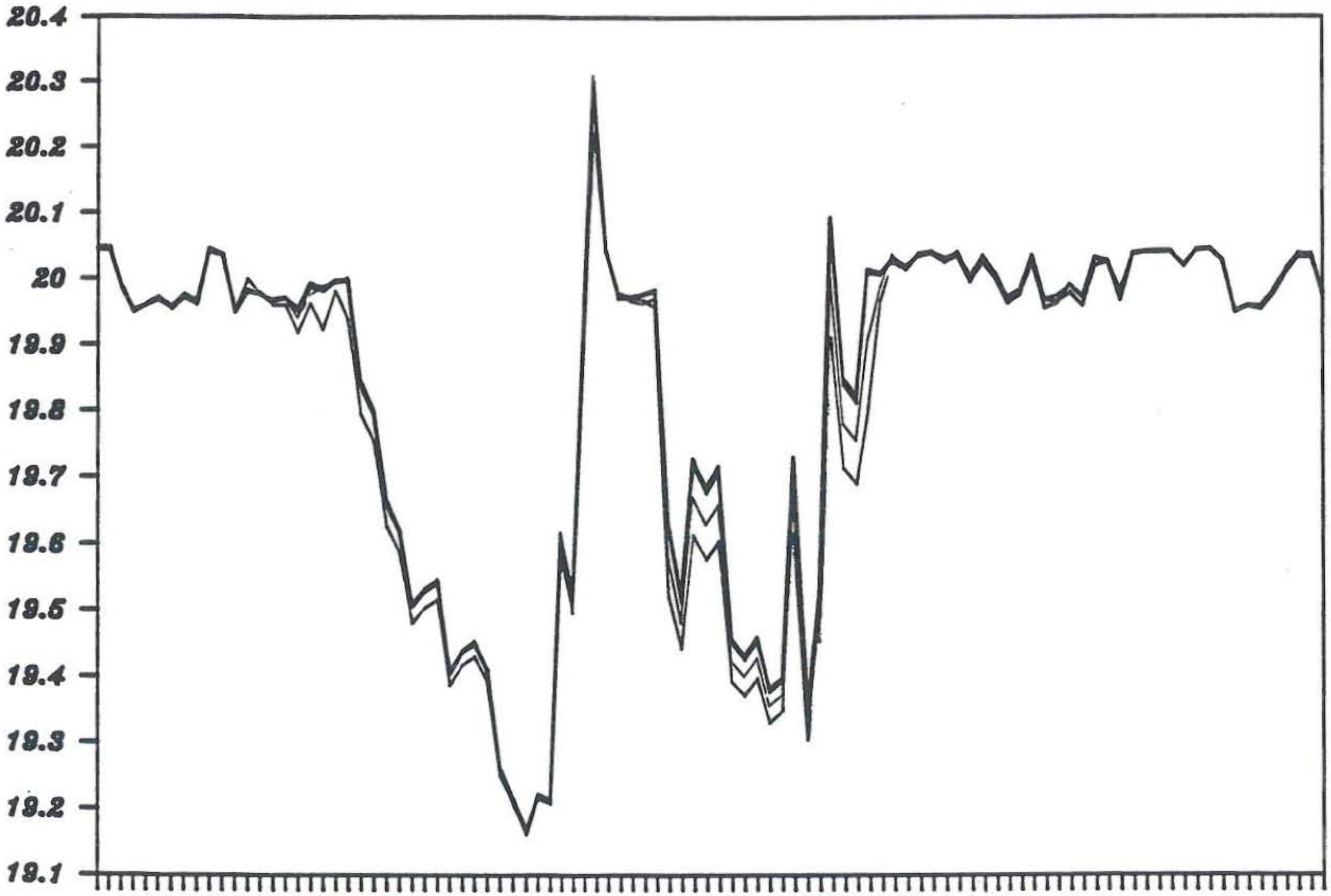


Figure 11 - Simulated indoor temperature for the 90/70 systems.

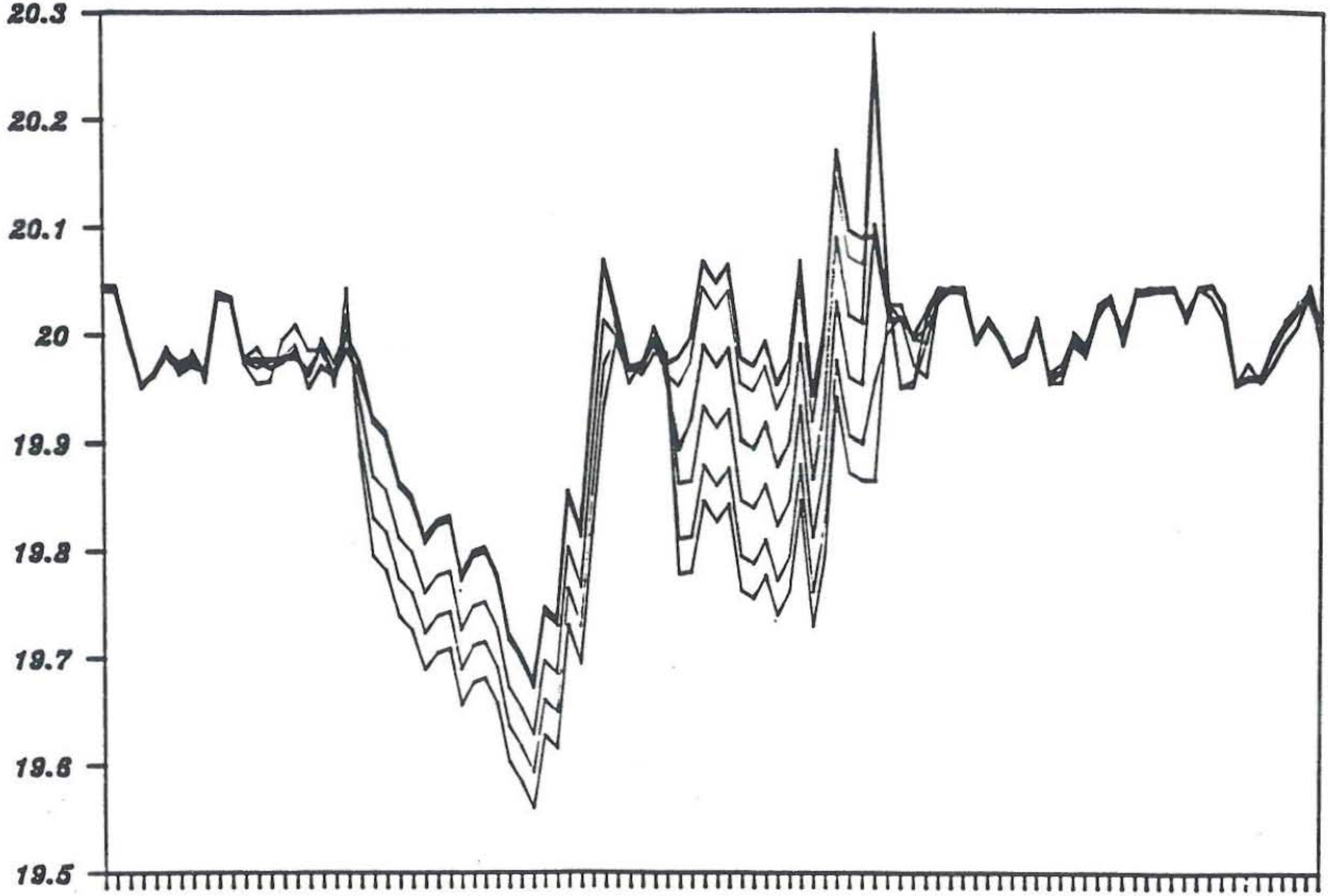


Figure 12 - Simulated indoor temperature for the 80/40 systems.