PERGAMON

Building and Environment 35 (2000) 151–159

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Linear programming optimization of heat distribution in a district-heating system by valve adjustments and substation retrofit

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Received 7 July 1998; received in revised form 27 October 1998; accepted 8 February 1999

Abstract

The unbalanced distribution of heat in a district-heating system may be caused by the increase of hydraulic resistance of pipe network, decrease of heat transmittance of radiators inside buildings, and increase of heat transmittance of building envelope. This situation yields the overheating of some buildings and underheating of other buildings. A district-heating system is analyzed that consists of heat plant, primary pipe network, substation, secondary pipe network, and three buildings. A steady-state, bottom-up approach and the sequential linear programming is used to solve this optimization problem. Results show that significant improvement of thermal comfort may be reached by adjusting the valves of secondary pipe network and resizing of the substation heat exchanger.

1. Introduction

The most common problem with district-heating systems (DHS) is the unbalanced distribution of heat to end-users [1]. This may be caused by: the increase of hydraulic resistance of pipe network, decrease of heat transmittance of radiators inside buildings, and increase of heat transmittance of building envelope.

Unbalanced heat distribution yields in DHS and buildings the loss of thermal comfort and energy, the overheating of some buildings and underheating of other buildings. People in overheated buildings open windows to decrease the space temperature, and in underheated buildings they turn on additional heating devices (like fan-coil heaters) to increase space temperature [2].

To solve this problem and achieve thermal comfort in heated buildings and save energy, the hydraulic resistance of valves may be adjusted, and heat exchangers in substations resized [3].

A DHS is analyzed consisting of (Fig. 1) heat plant, primary pipe network, substation, secondary pipe network, and three buildings. A steady-state, bottom-up approach is used to design an energy module network corresponding to the DHS, and then derive a set of equations that describes the behavior of the system [4]. Furthermore, the sequential linear programming (SLP) method is used to solve the optimization problem [5].

Three basic cases of the unbalanced distribution of secondary hot water are considered: the first case is due to changes in the hydraulic resistance of the pipe network from design value; the second case is due to changes in the heat transmittance of radiators in heated buildings from design value; the third case is due to changes of the heat transmittance of building envelope from the design value.

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0360-1323/00/$ - see front matter
PII: S0360-1323(99)00013-X

Nomenclature

A	coefficient of the pump polynomial (Js^2 kg^{-3})
B	coefficient of the pump polynomial (Js kg^{-2})
C	coefficient of the pump polynomial (J kg^{-1})
c	specific heat (J kg^{-1} K^{-1})
k	hydraulic-resistance coefficient (Js^2 kg^{-3})
m	mass-flow rate (kg s^{-1})
T	temperature (K)
Y	energy that a pump delivers to unit fluid mass (J kg^{-1})
Z	heat-transmittance coefficient (W K^{-1})
ζ	hydraulic-resistance coefficient of valves (Js^2 kg^{-3})
∂T	the difference between indoor-air temperature and T_{TC}

Subscripts

A	building A
B	building B
C	building C
dg	fume gas
g	fuel
h	cooled
i	output
k	boiler
neg	negative
p	primary pipe network
pos	positive
r	radiators
s	secondary pipe network
sp	outdoor
TC	thermal comfort
t	hot
u	input
v	air
w	water
z	building envelope

2. Mathematical model

2.1. Description of the system

The district-heating system, considered in this paper, is shown in Fig. 1, and its energy-object network is presented in Fig. 2. Heat is transferred from the heat plant to building radiators by using two pipe networks: primary and secondary. In primary pipe network, heat goes from the heat plant to the substation by using the hot water. In the substation heat exchanger, this water is cooled from the temperature $T_{p,u}$ to the temperature

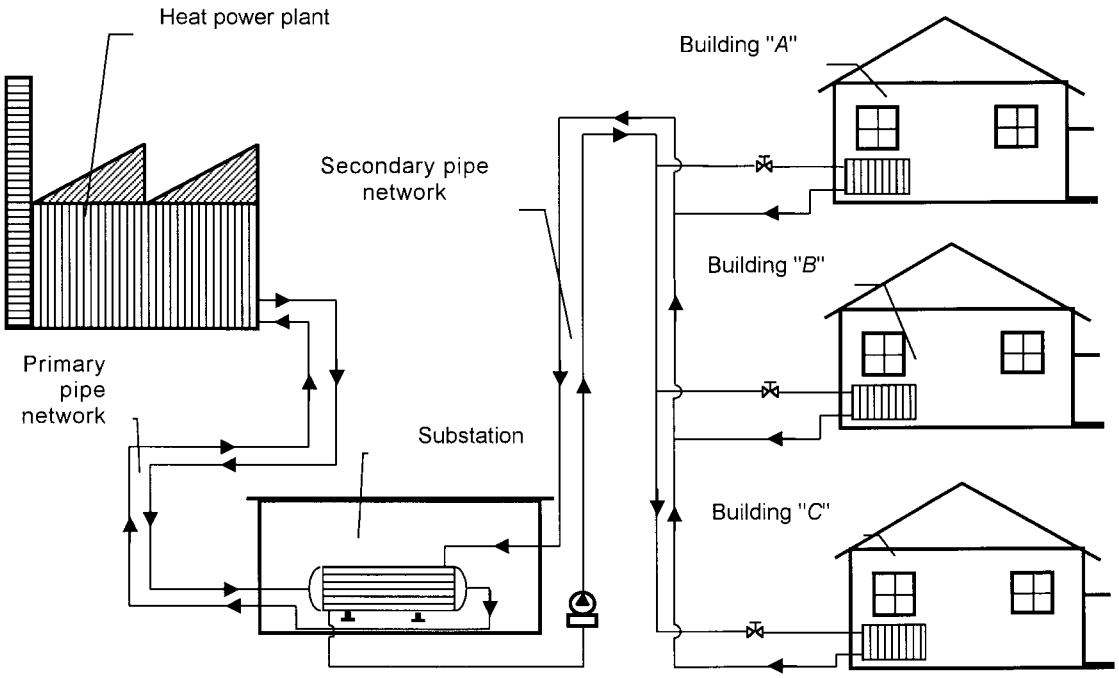

Fig. 1. Schematic of the district-heating system.