

# Quantitative heat loss determination by means of infrared thermography - The TX model (1996 N4)

## Summary

This report is the final report of the IEA District Heating Project, Annex 4, "Supervision of District Heating Networks. The aim of the project was to further analyze and verify a method developed earlier for determining the heat loss from buried district heating pipes by measuring the temperature profile on the ground surface above the pipes. The temperature measurements can be made by means of infrared (IR) thermography using equipment such as modern IR thermography cameras.

The report describes the work done in the four co-operating countries Denmark, Finland, Sweden and USA for verifying the TX model established in work performed in IEA, Annex 3. The TX model hypothesizes that the temperature distribution on the ground surface above the pipes corresponds - under certain circumstances - to the heat loss from the pipes. By including the major influences of the climate, especially of the wind and the changing surface temperature, we have derived a semi-empirical equation for the heat loss when the TX factor, i. e. the integral of the surface temperature profile across the pipe, is measured. This model is called the advanced TX-interpretation model ATXIM.

Two kinds of investigations have been performed during the verification phase: Simulations and experimental evaluations on test fields.

Simulations have been performed with a finite difference program simulating the heat flow in the ground and between the ground surface and the surroundings. A computer program developed earlier was modified for reading actual weather data based on hourly mean values. The program was used for simulating a multitude of cases with different climate and soil conditions. As a result of these studies we determined that the wind is a very important

parameter affecting the TX value. By including the mean wind velocity of the last 7 hours in the ATXIM, the agreement between the simulation and ATXIM could be significantly improved. Other important parameters are the burial depth of the pipes, and the change of the pipe temperatures during the preceding week.

In parallel, experimental evaluation of the TX model was carried out on test fields in the four countries with pipe systems where heat loss was monitored separately. In these test fields in Denmark, Sweden and USA, temperature and energy losses could be monitored continuously, and in some cases also the TX factor could be derived by measurements of the surface temperature profile with temperature sensors. We discovered, however, that IR measurements are the most reliable way of measuring the TX factor. When the ATXIM was applied to IR measurements of the TX factor on the three test fields, and also to a TX evaluation of earlier measurements on a test field carried out in Finland, the result was in reasonable agreement with the heat losses measured in conventional ways.

*Hence it can be concluded that under certain well controlled conditions, the heat loss of pipes in district heating networks can be determined quantitatively by analysing the TX profile. The TX profile is best measured using an IR thermography camera, of which there are a number commercially available. The surface must be uniform over the integration width which should be between 3.5 and 5 m. Thermography can be applied at both night and day conditions, but the surface of the test area must have been irradiated uniformly during the last hour, preferably longer. Wet surfaces and rain conditions must be avoided. Grass surfaces and uneven surfaces are difficult to evaluate. If these caveats are observed, it is expected that measurements will achieve an accuracy within  $\pm 20\%$ .*

## Introduction

In those countries which have used district heating for many years, a new concern has recently arisen: Certain district heating networks are approaching the end of their technical lifetimes and the heat loss in older piping networks has the potential to increase significantly. In order to chart the requirements and resources for maintenance measures, it is important to be able to diagnose the conditions of the piping network, most importantly the heat losses from the pipes.

Historically, several different methods have been used for determining the heat loss from buried pipes. A survey of these methods is given by Borgström, 1991. The most commonly used method of measuring heat losses from pipes has been to take out a pipe specimen to the laboratory and to measure the heat loss in a controlled steady-state experiment. Such type of measurements of different types of pipe systems including water pipe, insulation and outer casing has been performed by Carlsson et. al. 1963. In these experiments, temperature sensors and water flow meters were used for determining the overall heat loss from the pipes.

Jonasson, 1986, has performed measurements on prefabricated joint pipes by essentially measuring the temperature difference between distribution water and pipe casing, together with air and ground temperature, by means of thermocouples and comparing the results with theoretical expressions fitting the right set of parameters. Phetteplace et al., 1991, has conducted field experiments comparing several methods of measuring heat losses on operating systems. Benny Bøhm, 1990, introduced heat flux meters for measuring the heat loss from buried pipes and compared these results with results calculated from the measured temperature distribution in a section perpendicular to the pipe. The problem of heat flux meters has been attributed to their calibration with the surrounding (unknown)

ground properties. Margaretha Borgström, 1994, made a very detailed study of the heat loss from prefabricated pipes by means of heat flux meters. In this case however, the pipes were locally uncovered from all soil and hence the surrounding media was air and a well known shielding insulation.

One other method increasingly used for qualitative heat loss detection and status control of district heating networks is based on airborne and ground borne thermography. In this method the mapping of the ground temperature can be used to give qualitative information about the network condition, mainly with the aim of finding leaks ( Bartsch, 1979; Ljungberg, 1987; Hansen, 1987). These techniques rely primarily on relative changes of the temperature pattern along the pipe.

With the help of more refined analytical methods it should be ultimately possible not only to trace leaking media pipes, but also to determine the condition of the insulation. In the quantitative heat loss analysis, it is presumed that the temperature profile on the ground surface above the pipes, measured in the direction perpendicular to the pipe alignment, is related to the pipe heat loss. The basic idea is that the integral of the temperature variation across the pipe, called TX, is a function of the heat loss. Obviously TX is also affected by other parameters such as depth, heat diffusivity of the ground and so on. By including all of these parameters in an interpretation model it is proposed that one may determine the amount of heat loss quantitatively and hence to draw conclusions about a potential damage to the protective casing or the pipe (Perers, 1989; Perers and Jönsson, 1990). Figure 1 illustrates this basic idea.

A more detailed analysis of the TX model was carried out within the IEA - DH&C Program - Annex III and reported by NOVEM (Jönsson,

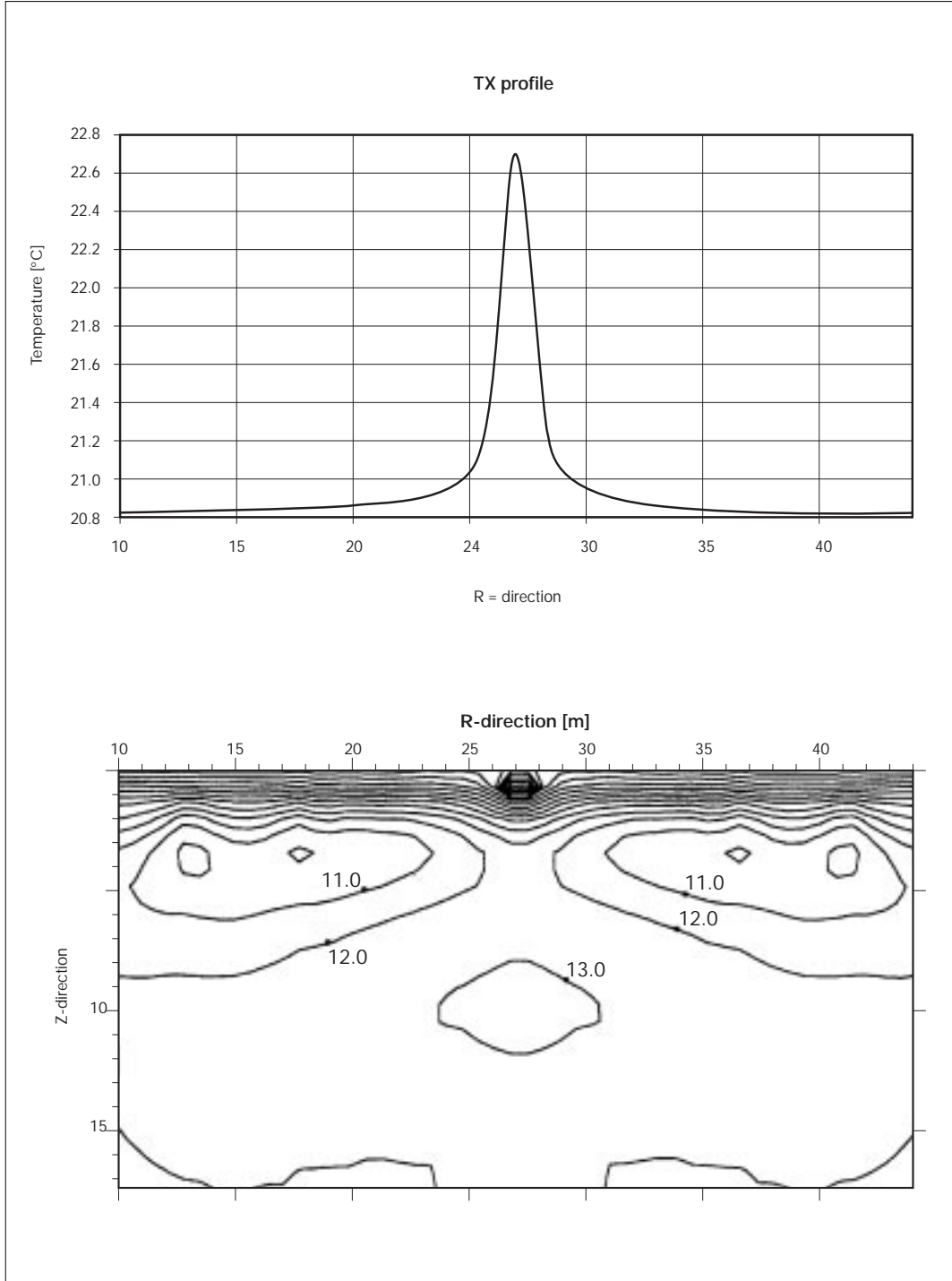


Figure 1: Thermography of buried district heating pipes and the TX-profile.

Zinko, 1992). The analysis was based on field measurements at Studsvik and on a ground simulation model that used finite difference techniques in combination with a model climate. The results were also tested in a limited field application.

In addition to a physical description of the pipe and of the surrounding ground, the finite element model includes freezing and evaporation of water in the ground and on the surface, solar radiation, snow, rain, condensation, convection, wind, and the exchange of IR radiation between the ground and the atmosphere and the surroundings, respectively. However, the interpretation model - called TX-model was derived for a limited set of conditions corresponding to variations of some of the parameters discussed above.

The objective of this phase of the project is to further develop and verify the method of IR heat loss evaluation on district heating pipes by means of the TX-model to determine its potential and limitations for determining the status of pipes and its possible use for planning service and maintenance on the network.

The work which has been carried out includes the following items:

- Installations of test sites for TX-measurements in different countries
- Modelling of test-sites with the ground model simulation program
- Experimental verification of the model with test-field results
- Refining the model by systematic sensitivity studies
- Application of the TX model in IR field surveys

### **Conclusions and Recommendations**

The following conclusions and recommendations can be drawn from our findings:

- The proposed model for quantitative thermography analyses has been shown to expand the range of applicability of conventional thermography evaluation. The TX model represents a possibility for the quantitative (instantaneous) determination of heat losses from buried pipes.
- Thermography during exposure to long wave and solar radiation is possible if the surface is uniformly exposed to the radiation and if it has a uniform emissivity within the surface area to be analyzed. The TX model can be applied under suitable conditions at both day and night.
- It has been shown that the wind has a very strong influence on the instantaneous TX factor. It is included in the Advanced TX Interpretation Model ATXIM. The ATXIM includes wind conditions during the last 7 hours before the thermography measurements. The model is verified for wind speeds up to 10 m/s.
- Rain conditions and wet and drying surfaces as well as frost in the ground are not suitable for quantitative heat loss analysis using the TX method.
- The following parameters are included in the ATXIM: Average wind speed over the last 7 hours, the thermal conductivity of the ground, the burial depth of pipes, and the integration half width X.
- Factors that can be optionally included are the changes of the surface temperature during the last 5 hours and of the pipe temperature during the last week.
- The thermal conductivity of the soil has - in contrast to a common opinion - only a relative small influence on the heat loss. The exact soil composition and the value must not be known precisely for determining the heat loss.
- Experimental verification of the model included a depth of 1.1 m and an integration width 2X up to 5 m. The burial depth of the buried pipes is an important parameter and should be known as closely as possible.

- The physical properties of the surface layer and the surface itself, as well as the irradiation, must be uniform.
- Asphalt shingles were shown to be useful as a reference cover on non uniform surfaces or surfaces with undefined physical properties.
- The TX model cannot be applied on grass surfaces and uneven surfaces.
- The error of the model should under suitable conditions be within  $\pm 20\%$ .
- We recommend further evaluation of the application of TX model as expressed by the ATXIM in the course of practical field thermography surveys in order to develop the procedure for a camera-integrated TX option.