Energy 73 (2014) 1007–1016

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Investigating the relationship between air and ground temperature variations in shallow depths in northern Greece

G. Tsilingiridis*, K. Papakostas

Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University, 541 24 Thessaloniki, Greece

ARTICLE INFO

Article history:
Received 16 November 2013
Received in revised form
30 June 2014
Accepted 2 July 2014
Available online 22 July 2014

Keywords:
Ground temperature
Ground-to-air temperature coupling
Ground temperature profile
Ground thermal behavior

ABSTRACT

In this paper the relationship between ground temperature and ambient air temperature is investigated in Northern Greece. To this end, 10 years records of daily average values of ambient air, bare and grass-covered ground surface, and ground under bare surface temperatures at depths of 0.02, 0.05, 0.10, 0.20, 0.50, 1.00 and 1.50 m measured by the Meteorological Station of Aristotle University of Thessaloniki are used.

Seasonal variation of surface and ground temperatures, time lag regarding ambient air temperature variations, as well as the vertical distribution of ground temperature up to 1.50 m, are examined and analyzed.

The ground-to-air temperature relation is examined by correlation of average daily, as well as monthly values, and best trend lines equations are defined in order to be used in technical applications. The defined analytical equations are evaluated by comparison of calculated and measured ground temperature values and a very good fitness is found.

1. Introduction

Information on ground temperatures is necessary for many applications. These include the design of GSHP (ground source heat pump) systems and EAHEs (earth-air heat exchangers), the calculations of heat losses of buildings, the sizing and design of underground power transmission and distribution systems and the plant growth, productivity and disease battling in agricultural greenhouses [1,2]. Important for all these applications are the soil thermal properties as well as the ground temperature variations with time and depth from the surface.

Ground temperatures are mainly affected by the structure and physical properties of the ground and the ambient air temperature variations [3–5]. Other climatic factors (e.g. solar radiation, wind, rainfall) and ground surface characteristics (bare ground, lawn) also influence ground temperature to a greater or lesser extent. Generally three temperature zones are observed [6]: (1) the near surface zone, where the ground temperature is sensitive to diurnal variations, (2) the shallow zone, where the ground is sensitive to seasonal weather variations and (3) the deep zone, where the ground temperature is maintained almost constant. Below the depth of 15 m temperatures can be considered approximately equal to the annual average ambient air temperature. The amplitude of the diurnal and seasonal variations of ground temperature decreases with depth, while the time lag in relation to the ambient air temperature increases.

The ground has a thermal behavior milder and more stable if compared with external environment since it has an immense mass and it works as a huge thermal reservoir for the solar energy that falls on its surface [3,7]. Because of this characteristic, ground temperatures are lower during summer and higher during winter in relation to the ambient temperatures. This is very beneficial for the dimensioning, performance and installation costs of GSHP systems and EAHEs. These systems are exploiting ground thermal capacity and consist of vertical or horizontal underground tubes or air ducts, where water or air is circulating before entering in a building for heating or cooling purposes, in connection with a heat pump system. Tubes in vertical GSHP systems are installed at depths up to 300 m, while in horizontal systems at a depth up to 2 m [8]. The air ducts of EAHEs are usually buried at a depth of 1.5–3 m.

Research on ground temperature in different depths and available time series of ground temperature measurements are limited, especially for technical engineering applications. This fact along with the increasing demand for environmentally friendly technologies, necessitate the study of the energy accumulated in the ground. Most early studies on ground temperature investigated the development and the evaluation of mathematical models to predict the ground temperature variations and the thermal flux in various

* Corresponding author. Tel.: +30 2310996084; fax: +30 2310996087.
E-mail addresses: tsil@eng.auth.gr, tsil@auth.gr (G. Tsilingiridis).

http://dx.doi.org/10.1016/j.energy.2014.07.004
0360-5442/

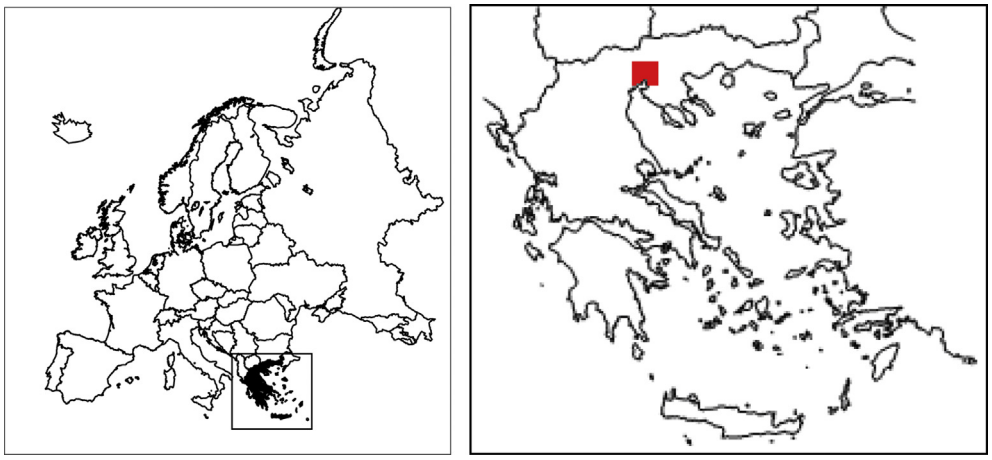

Fig. 1. Site of meteorological station of IMC/AUTh in Northern Greece.

depths [9–14]. They were based mostly on measurements at ground surface or at shallow depths, while measurements for higher depths are few.

On the other hand, most of recently published studies turned to investigate variations of ground temperature at various depths (up to 180 m), ground properties as well as geothermal characteristics of the ground, the influence of ground surface cover (grass, snow, asphalt) on ground temperature, or the technical and economic factors that influence the design and performance of the necessary equipment, aiming to facilitate thermal applications, especially with GSHPs or EAHEs [15–23].

The most ground temperature studies in Greece investigated the temporal variation of ground temperature and the influence of ground cover on it, the use of ground as heat exchanger for heating/cooling of buildings, the temperature distribution below buildings and the cooling potential of earth, or they present results of simulation/prediction models [24–29]. All these studies use measurements of ground temperature up to 1.20 m, available from the meteorological station of the National Observatory of Athens, in Central Greece.

Studies of ground temperature in other sites in Greece are limited, except a few published works referring to Northern Greece. These studies investigate seasonal variations of ground temperature in order to improve knowledge useful for agriculture [30], or study the soil temperature, the directions of heat flux, and the conditions favoring temperature-induced water vapor flux [5]. The results of these studies are useful for agricultural activities, such as sowing, planting, or plant growth and yield. Both studies are based on measurements from Meteorological Station of Aristotle University of Thessaloniki, conducted three times per day (in hours 08:00, 14:00 and 20:00). The first study [30] is based on the 1953–1973 period ground temperatures at depths of 0.02, 0.05, 0.10, 0.25 and 0.50 m, which were analyzed integrated in average seasonal values (winter, spring, summer and autumn). The second study [5] is based on the 1961–1970 period air and ground temperatures at depths of 0.02, 0.05, 0.10, 0.25, 0.50 and 1.20 m, which were analyzed integrated in average values of ten-days (36 periods per year).

In the present paper results from the investigation of ground temperature variation with time and its distribution in various depths are reported. A multiyear data set of air and ground temperatures recorded by the Institute of Meteorology and Climatology of Aristotle University of Thessaloniki (IMC/AUTh) in Northern Greece was used for this study. The meteorological station of AUTh is one of the two sites in Greece, where time series of ground temperatures in depths up to 1.50 m are available.

The major aim is to investigate the relationship between ambient air and ground temperatures in various depths and to propose simple equations for calculation of the monthly average ground temperature in conjunction with the air temperature, which is a physical quantity that can easily be obtained from meteorological stations providing the necessary time series measurements.

Such analytical equations could be useful for technical engineering applications, since the acquisition of a time series of temperature measurements in a place of interest is a time consuming procedure and it requires special skills for installing and operating the necessary instruments.

2. Methodology

2.1. Site description and instrumentation

Air, ground surface and subsurface temperatures in various depths were examined in this study. Temperature data were measured by IMC/AUTh in Northern Greece (see Fig. 1). The meteorological station of the IMC/AUTh was founded in 1929 and is situated in the center of Aristotle University, 31 m above sea level (latitude 40°37′N, longitude 22°57′E). Since 1959, it operates in the present position (220 m E–NE from the previous one). Measurements of soil temperatures were started on 1/1/1930. After the year 1979 measurements at depths below 0.10 m ceased and only recently temperature measurements at 0.20 and 0.40 m depth have been started again. For this reason the data set used in the present study contains ten (10) complete year measurements from 1970 to 1979 [31], the most recent decade with continuous and complete records.

In the area of the meteorological station the ground up to the measurements depth is nearly homogeneous with a loamy texture [5], while evidences of any abnormal geothermal gradient do not exist.

Available published data [31] include:

- Ambient air temperature at 08:00, 14:00, 20:00 LST (Local Standard Time, is 2 h ahead of GMT), in °C.
- Average, absolute maximum, and absolute minimum daily ambient air temperature, in °C.
- Average, absolute maximum and absolute minimum, daily surface temperature performed for bare and thick-grass-covered soil, in °C.