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Variations and trends of heating and cooling degree-days in Georgia for 1961–1990 year period

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ABSTRACT

Indoor air heating and cooling is responsible for a large fraction of energy use in Georgia. Heating and cooling degree days are measures that reflect the amount of energy needed to heat or cool a building to a comfortable temperature, considering how cold or hot it is outside.

The purpose of the presented research is to estimate and study variations and trends of heating and cooling degree days for different locations in Georgia for the base period defined by the World Meteorological Organization (1961–1990). To achieve this goal, air temperature daily values were used for fourteen different locations within Georgia, covering 1961–1990 year period. The daily, monthly and annual numbers of cooling and heating degree days have been estimated for various locations and also their spatial distribution have been studied. Heating degree days were calculated at a base temperature of 18 °C and cooling degree days at a base temperature of 26 °C.

The obtained results are significant to study energy demand and resolve environmental issues associated with energy consumption in Georgia.

Introduction

Energy is crucial for development of the country. United Nations Sustainable Development Goal (SDG) 7 seeks to ensure access to affordable, reliable, sustainable and modern energy for all [1]. For achieving this SDG first of all its important to assess energy demand in different physical-geographical regions and understand how this demand has been changing under global worming conditions. The degree-day method is an effective method to estimate energy demand for building heating and cooling. This method assumes that the energy needs for given building at a specific location are proportional to the number of heating degree days (HDD) or cooling degree days (CDD) [2–5]. Heating degree days are calculated by simple subtraction of the outdoor temperature from the base temperature, taking into account only positive values (6). The base temperature is defined as the outside temperature above which the building needs no heating. Cooling degree days are calculated from temperature above the base temperature, in this case base temperature is the outdoor temperature below which building needs no cooling [6–8]. Traditionally, cooling degree-days are determined at the base temperature of 22 °C, in USA heating degree-days are calculated at the base temperature of 18 °C, in the U.K at 15.5 °C. However, the average value of the base temperature is not the same everywhere; it varies widely from one location to another, as on the one hand it depends on various climatic variables, such as humidity, wind regime, etc. for the particular region, on the other hand its depends on building characteristics such as thermal insulation, air leakage etc. [9]. Hence, different base temperatures are used by different authors for various regions of the world. Papakostas et al. [10] studied HDD and CDD annual values for Greece two main cities: Athens and Thessaloniki from 1983 to 2002. For these study two base temperatures, namely 15 °C for heating and 24 °C for cooling were used. Moustris et al. (6) calculated heating degree-days at base temperature of 18 °C and Cooling degree-days at base temperature of 22 °C in different locations within the Greater Athens area, Greece for 2001–2005 year period. Orhan Buyukalaca et al. [9] used five different base temperatures ranging from 14 to 22 °C and six different base temperatures from 18 to 28 °C and estimated the heating and cooling degree-days for Turkey. Said [11] used different base temperatures and studied Heating degree days (HDDs) and Cooling degree days (CDDs) for Saudi Arabia. Kodah and El-Shaawari [12] analyzed the heating and cooling degree-days for Jordan and concluded that the heating base-temperature of 15.5 °C in Jordan is appropriate. Spinoni et al. [3] used the base

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Table 1
Stations used in the study and related information.

#	Station	Latitude	Longitude	Elevation (m)
1	Abastumani	41°45′9.15″N	42°49′55.30″E	1297
2	Batumi	41°38′19.07″N	41°38′15.05″E	5
3	Lentekhi	42°47′35.85″N	42°43′7.65″E	766
4	Mestia	43° 3′21.66″N	42°45′1.97″E	1445
5	Pasanauri	42°21′7.78″N	44°41′14.99″E	1080
6	Khulo	41°38′45.89″N	42°18′40.08″E	945
7	Dedoplistskaro	41°27′50.04″N	46° 6′39.49″E	836
8	Telavi	41°55′0.09″N	45°29′0.28″E	707
9	Sokhumi	43° 0′5.49″N	41° 1′24.30″E	8
10	Akhaltsikhe	41°38′20.17″N	42°59′10.18″E	962
11	Tbilisi	41°42′55.11″N	44°47′1.49″E	455
12	Kutaisi	42°15′58.47″N	42°43′4.81″E	188
13	Tsalka	41°35′52.65″N	44° 5′40.85″E	1470
14	Sabueti Mountain	42° 2′2.50″N	43°28′28.65″E	1252

temperatures: 15.5 °C for heating and 22 °C for cooling and studied European degree-day climatology and trends for 1951–2011 year period [3].

The aim of presented research is the estimation of Heating degree days (HDDs) and Cooling degree days (CDDs) for different physical-geographical locations of Georgia for (1961–1990) base period defined by the World Meteorological Organization, geoinformational mapping to study regularities of their spatial distribution.

Study area

Georgia is the mountainous country located in the South Caucasus between latitudes 41° and 44°N, and longitudes 40° and 47°E and occupies area of 69.875 km^2. Its population is about 3.718 million. The capital and largest city of Georgia is Tbilisi. Georgia is bounded on the north by Russia, on the east and southeast by Azerbaijan, on the south by Armenia and Turkey, and on the west by the Black Sea. There are mountains, valleys, plains, lowlands, glaciers, wetlands, arid lands, lakes, rivers and geysers in Georgia.

Part of lowlands is located at sea level while some of the mountain peaks reach over 5000 m above sea level. In the northern part of the territory from north-west to south-east stretches the Greater Caucasus ridge is stretched. The highest mountain in Georgia is Shkhara Peak located at 5201 meters above sea level. In the southern part of Georgia almost parallel to the Greater Caucasus Range extends South Georgian Highlands (part of the Lesser Caucasus). The Greater Caucasus Mountain Range plays the important role in moderating Georgia's climate and prevents the movement of cold air masses from the north over Georgia territory. The Lesser Caucasus Mountains partially protect the region from the influence of dry and hot air masses from the south, while humid warm air masses from the Black sea move easily over the western Georgia Territory. The Likhi Range, ranging from the north to the south connects the Greater Caucasus Range with the South Georgian Highlands and divides the country into two physical - geographical areas - Western and Eastern Georgia. Western Georgia is characterized by the humid subtropical climate, mild winters and hot summers with mean annual air temperatures of 13–15 °C and high annual precipitation values (1200–2400 mm). Eastern Georgia is characterized with transitional climate from humid subtropical to continental, annual precipitation (500–600 mm in the lowlands) and a mean temperature between 10 and 13 °C. In the mountainous areas mean temperature is within 5–10 °C range and precipitation varies from 800 to 1400 mm [13,14].

Data and method

In this study, database of daily mean air temperature of 14 meteorological stations of Georgia for 1961–1990 year period were used to calculate HDD and CDD. Information on meteorological stations is presented in Table 1. Stations were selected based on their physical geographical locations and complete daily data reliability and availability for the base period (1961–1990) defined by the World Meteorological Organization.

Equations (1) and (2) were used to calculate the daily values of HDD and CDD.

$$\mathrm{HDD} = (1\ \mathrm{day}) \times \mathrm{l}\ \mathrm{THb} - \mathrm{Tm}\ \mathrm{l} \quad (1)$$

Table 2
Mean monthly values of HDD and CDD (°C day) (at base temperature 18 °C and 26 °C) during the period 1961–1990.

Month		Abastumani	Batumi	Lentekhi	Mestia	Pasanauri	Khulo	Dedoplistskaro	Telavi	Sokhumi	Akhaltsikhe	Tbilisi	Kutaisi	Tsalka	Sabueti Mountain
January	HDD	708	337	623	734	668	521	569	523	373	667	501	391	689	660
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	HDD	611	302	511	620	561	456	501	452	318	561	429	332	619	589
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	HDD	532	297	426	555	484	411	432	370	286	459	343	276	558	547
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	HDD	348	186	245	367	295	246	235	181	163	267	160	142	369	360
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	HDD	221	72	114	229	180	136	98	61	68	141	44	54	241	237
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	HDD	126	0	40	134	78	66	26	12	0	55	0	0	132	135
	CDD	0	0	0	0	0	0	0	10	10	0	20	10	0	0
July	HDD	45	0	7	57	21	26	0	0	0	10	0	0	57	73
	CDD	0	10	10	0	0	0	30	60	2	0	130	60	0	0
August	HDD	55	0	10	75	29	30	0	0	0	13	0	0	76	76
	CDD	0	10	0	0	10	5	6	20	20	0	60	50	0	0
September	HDD	154	0	77	185	112	80	53	31	12	83	17	12	175	160
	CDD	0	0	0	0	0	0	0	0	0	0	20	10	0	0
October	HDD	330	75	252	350	279	194	219	172	88	261	142	87	341	317
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	HDD	473	170	406	495	426	312	355	308	187	420	296	191	464	441
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	HDD	635	270	572	671	593	457	498	455	308	595	442	320	606	585
	CDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual sum	HDD	4238	1709	3283	4472	3726	2935	2986	2565	1803	3532	2374	1805	4327	4180
	CDD	0	20	10	0	10	5	36	90	32	0	230	130	0	0