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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.

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

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

$$CDD = (1 \text{ day}) \times \text{l } Tm - TCb \text{ l} \quad (2)$$

where Tm is daily mean air temperature, THb is the base temperatures for HDD and TCb is the base temperatures for CDD.

Daily heating degree-days were calculated at the base temperature of 18 °C and cooling degree-days were determined at the base temperature of 26 °C. The base temperature was chosen considering year time and outdoor temperature when the heating and cooling system is operating in majority of buildings in Georgia. The daily values of CDD and HDD were summed giving the monthly values and, then, the monthly values were added up to get the annual values of CDD and HDD for 1961–1990 year period.

Results and discussion

In Table 2 there are presented the mean monthly values and the annual values of HDD and CDD, for all selected meteorological stations of Georgia calculated from daily mean temperatures of 1961–1990 period.

As it is evident from Table 2 there are significant differences between the monthly values of heating degree-days for different locations. Positive differences (THb − Tm > 0) are observed from October to May in all stations. Joint positive differences (THb − Tm > 0) and (Tm − TCb > 0) are observed from September to June in all stations. While positive differences (Tm − TCb > 0) are observed only in a few months from June to September in some stations only.

Monthly decadal trends of HDD and CDD for 14 stations of Georgia are illustrated on Fig. 1.

In April decadal trends of HDD are negative at all stations. In Abastumani, Mestia and Tsalka decadal trends of HDD are negative also in July, August and September; In Dedoplistskaro and Telavi in June and September; In Tbilisi and Khulo in September; In Lentekhi in July and August; In Sabueti Mountain in August and September; In Pasanauri in June, July, August and September. Though, the highest negative value of decadal trends which is ranging from 20 to 3 is detected in April in all stations. HDD mean annual decreasing in April reaches 2 °C day in Dedoplistskaro and in Batumi and Sokhumi 0,4 and 0,3 °C day. Dedoplistskaro is located in the most arid region of Georgia while Batumi and Sokhumi are humid regions of Georgia on the Black Sea shore.

HDD Decadal trends in all winter months are positive for selected 14 stations. The highest positive value of decadal trends in all stations is in November or December except of Akhaltsikhe, where the highest positive value of decadal trend is in April. HDD mean annual increase reaches 2,5 °C day in Batumi and Sokhumi in December and in Khulo in November. In all other stations HDD mean monthly annual growth is lower than 2,5 °C day.

Yearly decadal trends are positive in all examined station with the maximum values in Sokhumi and Khulo 87, 86 and minimum in Dedoplistskaro - 6° days per decade (Fig. 2).

According to Table 2, for Batumi, Sokhumi and Kutaisi HDD annual numbers is about 2,5 times lower than the corresponding numbers of Mestia, Abastumani, Tsalka and Mta-Sabueti. This shows that buildings with same characteristics in Mestia, Abastumani, Tsalka and Sabueti Mountain needs 2,5 times more heating energy than in Batumi, Sokhumi and Kutaisi.

A building in Lentekhi, Pasanauri, Akhaltsikhe needs about 2 times more heating energy than a building located in Batumi, Sokhumi and Kutaisi, and a building in Dedoplistskaro, Telavi and Tbilisi needs about 1,5 times more heating energy than a building located in Batumi, Sokhumi and Kutaisi both having the same characteristics.

HDD (°C day) annual spatial distribution of Georgia for 1961–1990 period is presented on Fig. 3.

In addition, it seems that stations can be divided in six groups according to HDD annual numbers (Fig. 3.). Stations Mestia, Abastumani, Tsalka and Sabueti Mountain (located - at the 1250–1470 m above sea level) belong to the firs group. For these stations HDD annual numbers is between 4000 and 4500 °C day. For the second group of stations:

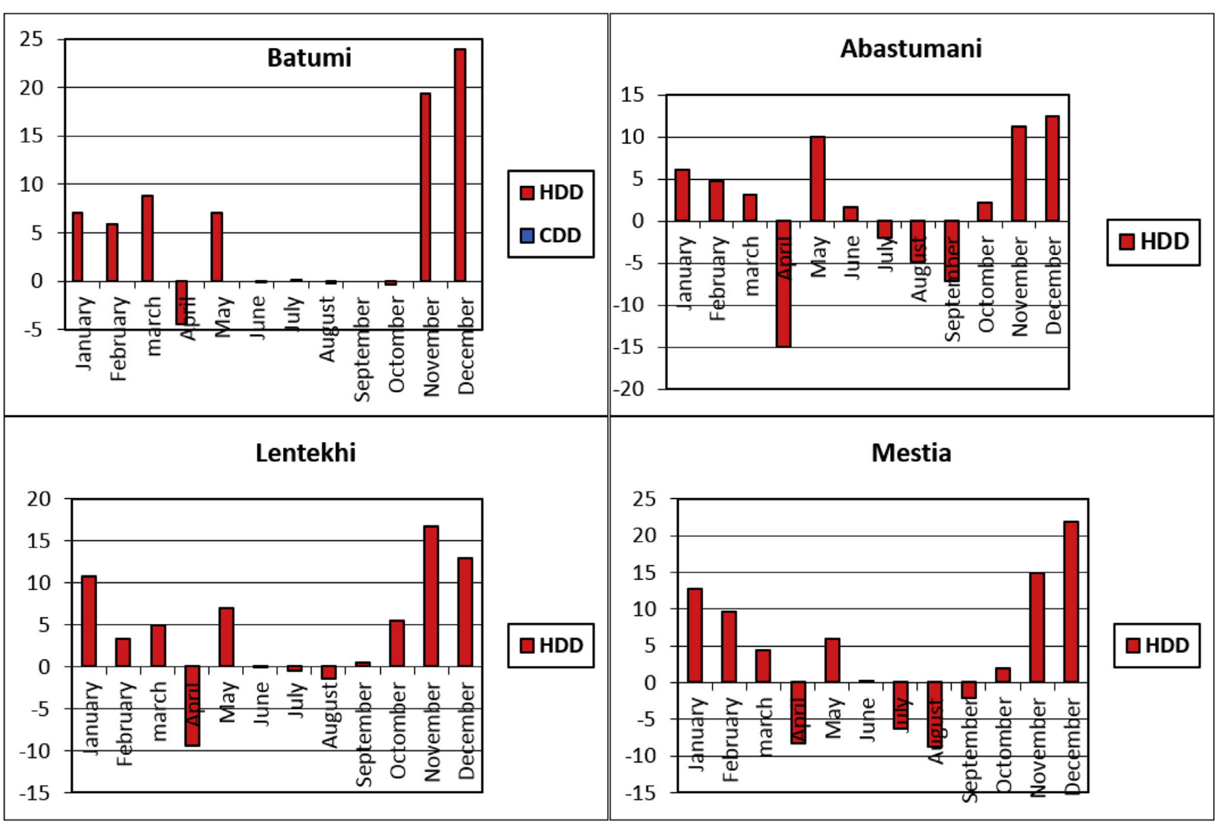

Fig. 1. Decadal trends in monthly HDD and CDD (°C day per decade) in 14 stations of Georgia.

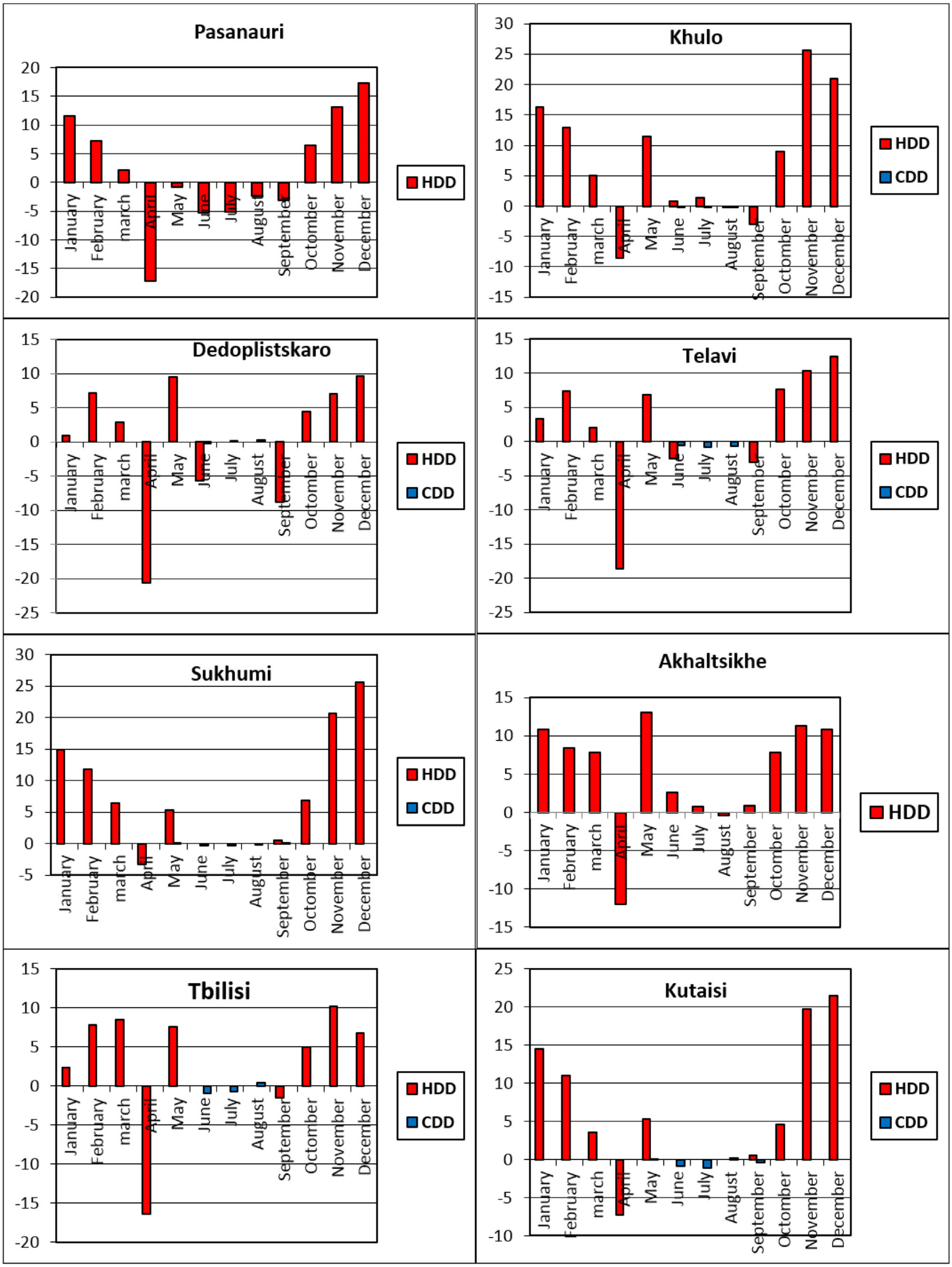

Fig. 1. (*continued*)

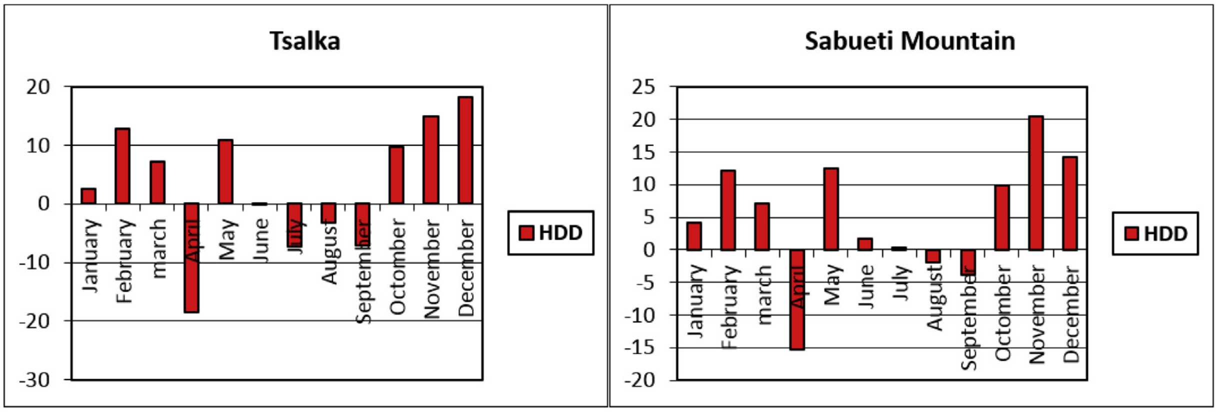

Fig. 1. (*continued*)

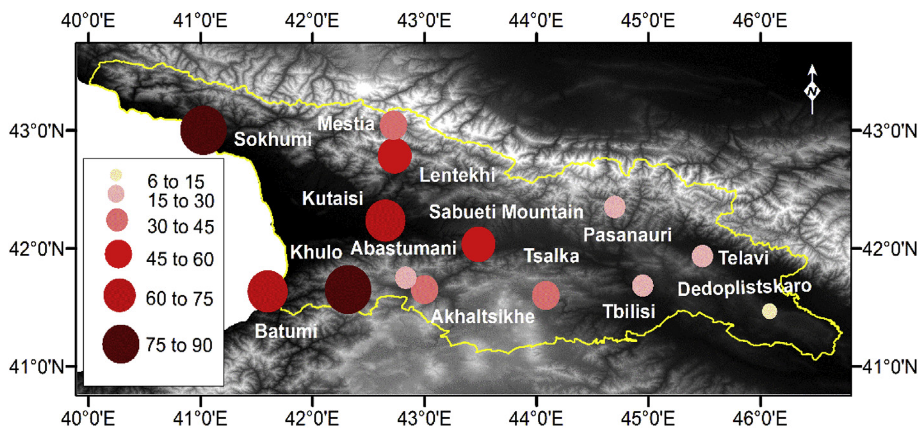

Fig. 2. Decadal trends in yearly HDD (°C day per decade) in 14 stations of Georgia.

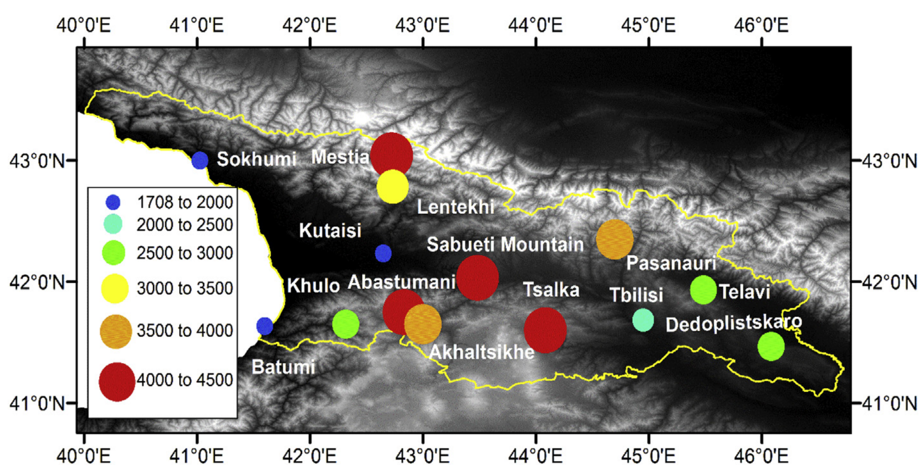

Fig. 3. HDD (°C day) annual spatial distribution of Georgia for 1961-1990period.

Akhaltsikhe and Pasanaurithe annual HDD is between 3500 and 4000, while it is about 3280 for Lentekhi, for Dedoplistskaro, Telavi and Khulo (fourth group of stations) HDD is between 2500 and 3000. For Tbilisi HDD is 2370. In the sixth group are the following stations: Batumi, Sokhumi and Kutaisi (located - at the 5–190 m above sea level) with HDD lowest annual numbers- 1700–2000. Fig. 3 shows clearly the peculiarities of climate of Georgia. For locations near to the sea coast, the heating degree-days have lower values compared with the eastern and the mountain regions. HDD value increases with elevation (Fig. 4.). Elevation of the meteorological stations used in this study varies between 5 and 1470 m.

Furthermore, according to Table 2, CDD annual number is the highest in the capital of Georgia – Tbilisi and then in Kutaisi (the second largest city in Georgia). For the rest stations CDD annual number is very low or has zero value. It is obvious that during the warm period of the year, the energy demand for cooling for a given building is greater in Tbilisi and Kutaisi than in other cities/towns. This can be connected to the urbanization impact.

Throughout the examined period in 11 stations, the values of HDD on daily basis range from 0 to 42 °C day. The frequency distribution of HDD values was examined, taking into account four classes (class range of 12 °C day, and 6 °C day). Results are presented in Table 3. In Mestia, Tsalka and Akhaltsikhe the daily HDD in some cases is more than 36 °C day.

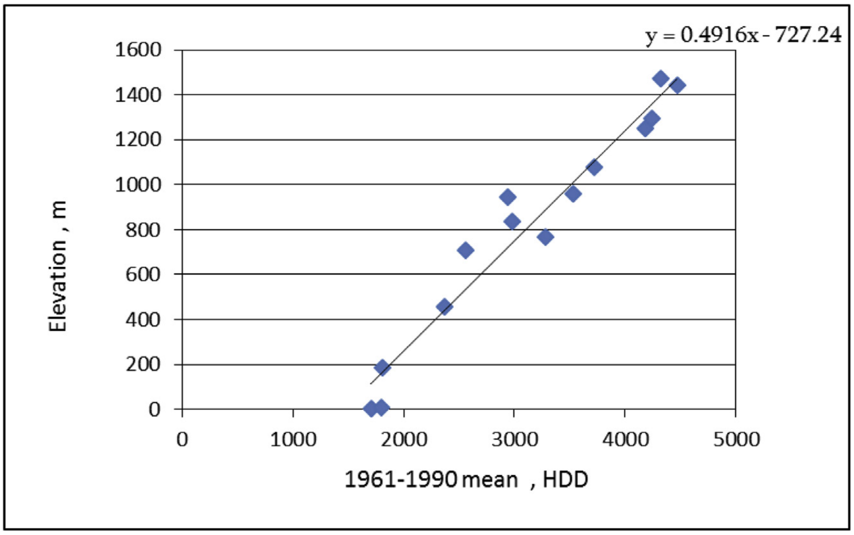

Fig. 4. Variations of 1961–1990 yearly mean HDD with elevation for Georgia.

From the results presented in Table 4 we can deduce that for the stations: Batumi, Sokhumi, Kutaisi 83,9 to 76,9% of the HDD values are less than 12 °C day, against 49,1–63% for the rest of stations. For the stations: Batumi, Sokhumi, Kutaisi 16,1 to 23,1% of HDD values are more than 12 °C day and less than 24 °C day, against 36,3 to 44,3% for the rest of stations. This means that the requirements for building heating in Batumi, Sokhumi, Kutaisi are lower in comparison to other stations.

Regarding CDD, they vary from 0 to 8 °C day, so four equivalence classes (range of 2 °C day) were selected for the interpretation of CDD frequency distribution. The results are presented in Table 4.

For Lentekhi, Abastumani, Akhaltsikhe 100% of the CDD values are less than 2 °C day. For Abastumani, Mestia, Tsalka and Sabueti Mountain there is no energy requirement for cooling. Thus, in Georgia the energy requirements for cooling are not so high compared to energy requirements for heating.

For each one of the fourteen meteorological stations of Georgia, the minimum, maximum and mean values of HDD and CDD as well as the standard deviations, for the period 1961–1990 were calculated. Results are presented in Figs. 5 and 6. In Fig. 5, it can be seen that, the mean value (center of the box), the absolute maximum value (whiskers) and the standard deviation (box), of HDD are increasing according to the meteorological stations elevation. Thus, the energy requirements for heating are higher in mountains than the lowlands.

Furthermore, the HDD maximum value appeared on the same day (25.01.1972, 24.01.1972, 20.01.1972) for the six of the fourteen examined stations. More specifically, on 25.01.1972 HDD reached maximum at Tbilisi, Telavi, Dedoplistskaro, Sabueti Mountain, Tsalka, Abastumani, on 24.01.1972 HDD reached maximum at Pasanauti, and on 20.01.1972 HDD reached maximum at Akhaltsikhe. This means that January 25, 1972 was the coldest day of the examined 1961–1990 period. Another coldest day of the same period was January 19, 1964 as on this day HDD reached maximum at Mestia, Lentekhi and Khulo, and on 29.01.1964 HDD reached maximum at Kutaisi and Sokumi. February 22, 1985 was the coldest day in Batumi of 1961–1990 period, as on that day HDD reached maximum value.

Conclusion

In this study, daily, monthly and annual HDD and CDD for fourteen different sites of Georgia have been estimated based on daily mean air temperature data for 30-year period (1961–1990).

The results show significant difference for HDD and CDD among the fourteen examined cities of Georgia.

Maps of annual HDDs and their trends are presented. HDD map and trends reflect many patterns concerning surface features and climate peculiarities of Georgia.

For Batumi, Sokhumi and Kutaisi, HDD annual numbers is about 2,5 times lower than the corresponding number of Mestia, Abastumani, Tsalka and Sabueti Mountain. The HDD value increases with elevation. In addition, the annual CDD number is the highest in the capital city of Georgia – Tbilisi and then in Kutaisi. In the rest stations CDD annual number is very low or is equal to zero which means that there is not cooling requirement in the most of the territory of Georgia at the base temperature of 26.

It is obvious that during the warm period of the year, the energy demand for cooling for a given building is greater in Tbilisi and Kutaisi than the other cities/towns. This can be connected to the urbanization effect.

Statistically significant and increasing HDD trends exist in all 14 stations in October, November, December, January, February, and March. In April decadal HDD trends are negative in all stations ranging between −20° days per decade in Dedoplistskaro (Easterner plain region of Georgia) to about-4 in Batumi and Sokhumi (Black sea coast). This is connected with the increase of daily maximum temperatures in April during 1961–1990 period.

Yearly decadal trends are positive in all examined stations with the maximum values in Sokhumi and Khulo 87, 86 and minimum in Dedoplistskaro - 6° days per decade.

87° days per decade is about 5% of the annual mean HDDs in Sokhumi and 86 is 3% of annual mean HDDs in Khulo. Thus there was very small or almost no changes of HDDs or CDDs from year to year in all fourteen stations of Georgia during1961–1990 period.

The maximum daily HDD in Sokhumi is 24 °C degree day, in Khulo - 29, in Tsalka- 42, in Mestia −38, in Akhltsikhe - 37. The Maximum CDD daily value in Kutaisi is 8 °C degree day.

Furthermore, the HDD maximum value appeared on the same day (25.01.1972) for the six out of the fourteen examined stations.

In conclusion, it is necessary to conduct similar survey for 1990–2017 period in order to assess energy demand change under the Global Warming conditions in Georgia compared to the base period defined by the World Meteorological Organization (1961–1990).

Table 3
HDD frequency distribution during 1961–1990 period.

HDD (°C day)	Abastumani(%)	Batumi(%)	Lentekhi(%)	Mestia(%)	Pasanauri(%)	Khulo(%)	Dedoplistskaro(%)	Telavi(%)	Sokhumi(%)	Akhaltsikhe(%)	Tbilisi(%)	Kutaisi(%)	Tsalka(%)	Sabueti Mountain(%)
0 < HDD < 12	49.6	83.9	52.8	49.18	53.4	63.0	54.9	59.7	79.3	52.3	59.9	76.9	51.2	52.1
12 < HDD < 24	43.0	16.1	44.3	41.4	41.7	36.3	43.3	39.5	20.7	41.69	39.6	23.1	41.4	43.3
24 < HDD < 36	7.4	0	2.9	9.4	4.9	0.7	1.8	0.8	0.0	6.0	0.5	0	7.37	4.6
36 < HDD < 42	0	0	0	0.02	0	0	0	0	0	0.01	0	0	0.03	0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 4
CDD frequency distribution during the period 1961–1990.

CDD (°C day)	Abastumani(%)	Batumi(%)	Lentekhi(%)	Mestia(%)	Pasanauri(%)	Khulo(%)	Dedoplistskaro(%)	Telavi(%)	Sokhumi(%)	Akhaltsikhe(%)	Tbilisi(%)	Kutaisi(%)	Tsalka(%)	Sabueti Mountain(%)
0 < CDD < 2	0	95.8	100	0	100	75	86	83.1	84.4	100	78.4	65.9	0	0
2 < CDD < 4	0	4.2	0	0	0	16.7	14	15.6	13.3	0	20.2	23.2	0	0
4 < CDD < 6	0	0	0	0	0	8.3	0	1.3	2.3	0	1.5	10.9	0	0
6 < CDD < 8	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Total	0	100	100	0	100	100	100	100	100	100	100	100	0	0

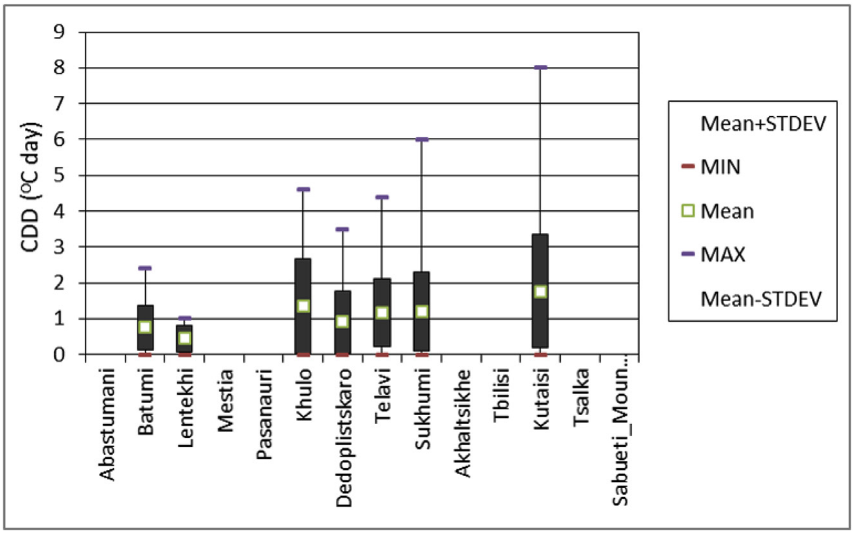

Fig. 5. The standard deviation and the minimum, maximum, mean values of HDD during the period 1961–1990.

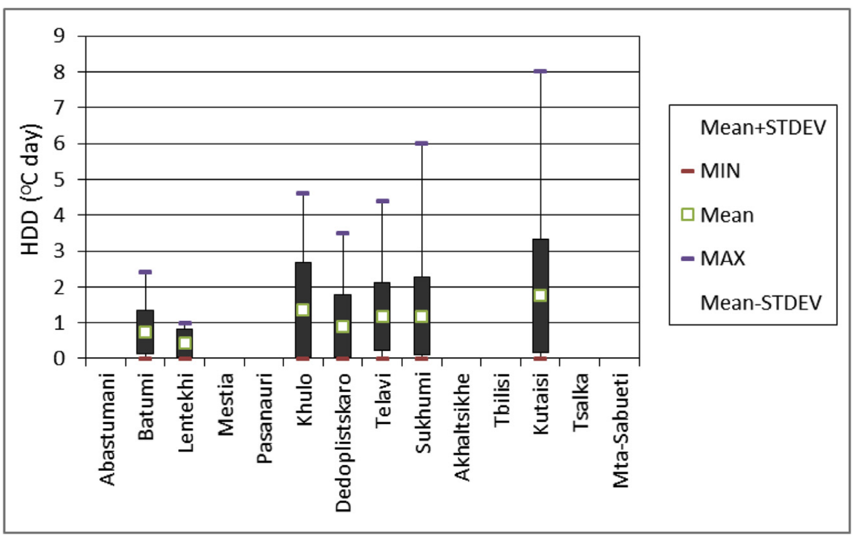

Fig. 6. The standard deviation and the minimum, maximum, mean values of CDD during the period 1961–1990.

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