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CASE STUDY

Analysis and mapping of the HDD, CDD and temperatures for southern Caspian Sea (CS) Based Model EH5OM

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ABSTRACT: In this paper the impact of climate change on southern Caspian Sea (CS) building energy demand was investigated by means of the degree-days method. Estimate heating degree-days (HDD) and cooling degree-days (CDD) from annual and seasonal simulated temperature data are required. To this end, data were received from EH5OM, the website of the Abdus Salam International Theoretical Physics Center (Italy). These data were run from 2015 to 2050 under A1 B scenario by the Intergovernmental Panel on Climate Change. For downscaling purposes, the fourth version of RegCM4 was used Heating and cooling degree-day with 18.3°C and 23.9°C temperature thresholds were calculated and then sum of annual and seasonal means of degree- day were obtained. The Results show that, at the northwestern corner of the Golestan province parts, the maximum temperature is observed; while in the southern parts of the Gilan and Mazandaran province minimum is recorded. Also a strong inverse relationship between temperature and elevation is observed. The lowest Annual energy consumption for Cooling would take place in the south Gilan province and so west and south Mazandaran province; while the highest energy consumption would be observed in the regions have low elevation, such as the northeastern Golestan province. The CDD values are negatively related to elevation and positively related to longitude and latitude.

Keywords: Heating degree-day, cooling degree-day, spatial distributions, Caspian Sea

RUNNING TITLE: Analysis and mapping of the HDD, CDD and temperatures for southern Caspian Sea

INTRODUCTION

At present the two principal policy approaches to global warming include actions to reduce the causes of climate change (mitigation) and adapting to the impacts of climate change (adaptation); the kinds of policy agendas that mitigation and adaptation respond to are somewhat distinct. Whereas climate change mitigation is about preventing further global climate change, climate change adaptation is about coping with local climate change. Until recently mitigation was commonly accepted as the dominant paradigm, but adaptation policies are receiving more attention in part because anthropogenic climate change appears unavoidable (Jennings, 2011). However, Developing countries are vulnerable to climate changes, primarily because of their limited adaptive capacities (Pouliotte et al,. 2009; Zarghami et al,. 2011).

Climate observations in recent years indicate that the effects of climate change events are apparently having an increasing impact on society. These impacts will likely also affect the building sector. Numerous studies have been conducted to assess future building energy

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consumption rates. However, these studies often do not take into account climatic variability and consumer reactions towards a temperature shift (Yau and Hasbi, 2013). Currently, climate change has become a research priority. In many countries, new regulations have emerged with the aim of reducing energy consumption and CO2 emissions (Rosselló-Batle et al., 2015).

Degree-days are a versatile climatic indicator and used for many applications in the design and operation of energy efficient buildings – from the estimation of energy consumption and carbon emissions due to space heating and cooling to the energy and environmental monitoring of buildings (Mourshed, 2012).

Several studies to date have concentrated on the analysis of temperature and indices of climate extremes based on data EH5OM (e.g., Branković et al, 2010; Omidvar et al, 2016; Omidvar et al, 2017; Mazidi et al, 2017); and studies the others focused on Estimate heating degree-days (HDD) and cooling degree-days (CDD) (e.g., OrtizBeviá et al, 2012; Al-Hadhrami, 2013; Cox et al, 2015; Idchabani et al, 2015; Omidvar et al, 2016; Abdurafikov et al, 2017). The use of degree-days method in the energy analysis of buildings is presented in several studies (Bolattürk 2008; Yu et al. 2009; Berger et al. 2014; Wang and Chen, 2014; Coskun et al. 2014; Borah et al. 2015; Csoknyai et al, 2016; Lindelöf, 2017).

This research is aimed calculating degree-days from temperature data by exploring the relationship between elevation and annual, seasonal mean temperature and degree-days of 83 cells in southern Caspian Sea (CS), is using Pearson Correlation; also zoning air temperature annual, seasonal data are downscaled the fourth version of RegCM4 in CS.

Materials and Methods

In this study, 36-year annual averages of heating and cooling degree-days are determined and presented for 83 different locations providing a spatial distribution of the degree-days for the case study (Fig. 1).

For assessing of effect elevation, latitude and longitude on the CDD and HDD of Pearson Correlation was used. Also Minitab 14 and MATLAB software is used to perform the abovementioned statistical analyses. Spatial distribution maps are generated using ArcGIS 9.3.

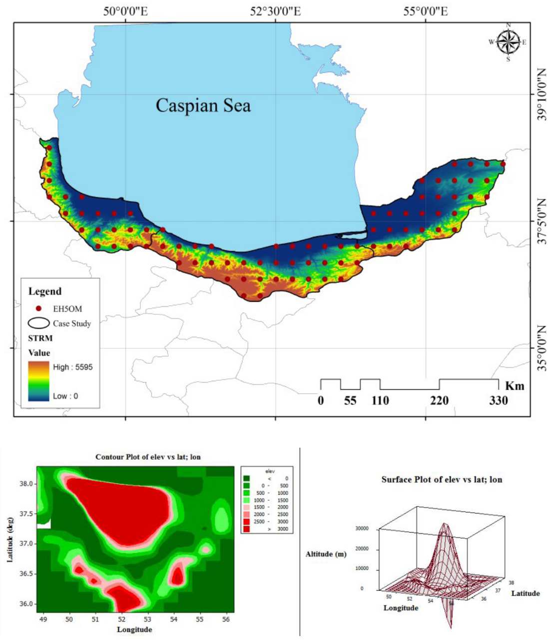

Fig 1. Station locations and corresponding elevations (in meters, left), contour graph (top right) and 3-D elevation distributions (bottom right) of stations with respect to latitude and longitude

Degree-Day Method

In this study, the CDD and the HDD for 82 different locations within the southern areas of the Caspian Sea were estimated for each season and annual, using values of air temperature from 82 different cells within the southern areas of the Caspian Sea. The air temperature data by the most recent version of the Max Planck Institute for Meteorology atmospheric general circulation model, ECHAM5 for a 30-year period (2015–2050) have been used. The primary data were drawn from EH5OM, The website of the Abdus Salam International Theoretical Physics Center (Italy). These data were run from 2015 to 2050 under A1 B scenario by the Intergovernmental Panel on Climate Change. For downscaling purposes, the fourth version of RegCM4 was used. For downscaling purposes, the fourth version of RegCM4 was used. Temperature data are downscaled with the geographical dimensions of 0.27 × 0.27 the length and width of which would approximately cover points with dimensions of 30 × 30 km area of case study. Heating and cooling degree-day with 18.3°C and 23.9°C temperature thresholds were calculated and then sum of season and annual means of degree-day were obtained. Finally, the sum of season and annual means of heating and cooling degree-day of the southern areas of the Caspian Sea was calculated and their maps were drawn.

Degree-days values are essentially the summation of temperature differences over time, and hence they capture both extremity and duration of outdoor temperatures. The temperature difference is between a reference temperature and the outdoor air temperature. The reference temperature is known as the base temperature which, for buildings, is a balance point temperature, that is, the outdoor temperature at which the heating (or cooling) systems do not need to run in order to maintain comfort conditions (CIBSE 2006; Idchabani et al, 2015). Also Degree-day is a measure of the energy requirement for heating and cooling of buildings. The degree-days of a time interval (monthly, seasonal, and annual) are defined as the summation of the temperature anomaly between the mean daily air temperature and the base temperature. A number of approaches have been used for computation of HDD and CDD (Jiang et al, 2009).

There are a few different ways of calculating HDD and CDD, regarding the availability of data and the integrating period. The most accurate calculation is using hourly data ($0 \le k \le 24$) of outdoor air temperature (T_i) and integrating directly using the base temperature. Equations (1) and (2) show the calculation formulae of the daily values of HDD and CDD using values of air temperature

$$HDD = \frac{\sum_{i=1}^{k} T_{Hb} - T_i}{24} \ \text{if} \ (T_{Hb} - T_i) > 0,\ 0 \le k \le 24$$

$$CDD = \frac{\sum_{i=1}^{k} T_i - T_{Cb}}{24} \ \text{if} \ (T_i - T_{Cb}) > 0,\ 0 \le k \le 24$$

Where T_{Hb} and T_{Cb} are the corresponding base temperature for HDD and CDD, respectively. For each month of the year, the daily values are summed giving the monthly values of CDD and HDD and, in the process, the annual values of CDD and HDD are estimated (Moustris *et al*, 205). As base temperature, the thresholds 23.9°and 18.3°C were considered for the calculation of CDD and HDD, respectively. This choice was based on researches (Roshan & Grab, 2012; Omidvar et al, 2016). Then Using ArcGIS 9.3, the spatial distributions of temperature, CDD and HDD for the base temperatures Model EH5OM are mapped.

RESULTS AND DISCUSSION

In this study, we considered Spatial distributions of annual average temperatures are determined for 84 different locations (cell) at the base on temperatures Model EH5OM (Fig. 2), spring (Fig. 3), summer (Fig. 4), fall (Fig. 5) and winter (Fig. 6). In these figures, the annual and seasonal average temperatures amounts have been interpolated case study. The findings show that, at the northwestern corner of the Golestan province parts, the maximum temperature is observed; while in the southern parts of the Gilan and Mazandaran province minimum is recorded. Also a strong inverse relationship between temperature and elevation is observed (Tab. 1).

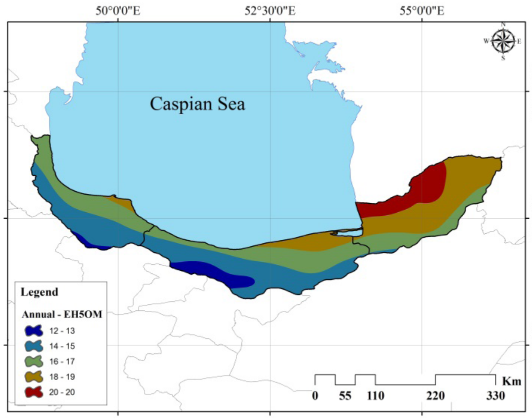

Fig 2. Zonation map of average annual temperatures over southern Caspian Sea in years 2015 to 2050 based on EH5OM

In the spring season, the highest temperature amounts are recorded on northwestern corner of the Golestan province. This region is a low height region, with an average temperature of 26 Celsius. The lowest spring temperature is observed in the western areas of Mazandaran province and south of Gilan province with 18-20 Celsius (Fig.3). In the summer season, the highest temperature amounts are recorded on northwestern corner of the Golestan province. In this season temperature decreases from the northwestern areas towards the west and southern regions. The lowest summer temperature is observed in the mid–southern areas of Mazandaran province with 23-24 Celsius (Fig.4). In the fall season, the highest value of autumn temperature occurs in the northwestern area of the Golestan province. The lowest autumn temperature is observed in the mid–southern areas of Gilan and Mazandaran province (Fig 5). In the winter season, the highest temperature amounts are recorded on northwestern corner of the Golestan province. The winter temperature decreases from the northwestern areas towards the southern regions. In the winter season, the thermal distributions were partly the same other seasons except spring in the southern areas of Caspian Sea (Fig. 6).

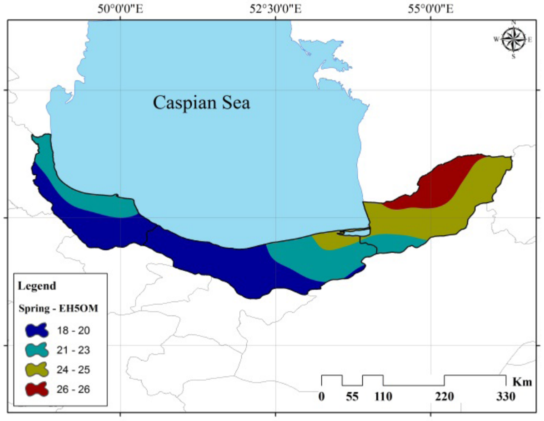

Fig 3. Zonation map of average Spring temperatures over southern Caspian Sea in years 2015 to 2050 based on EH5OM

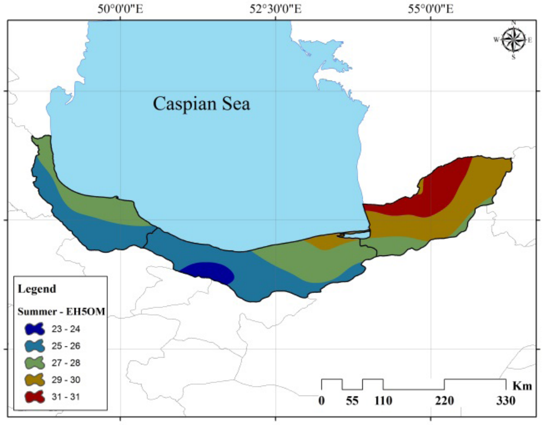

Fig 4 . Zonation map of average Summer temperatures over southern Caspian Sea in years 2015 to 2050 based on EH5OM

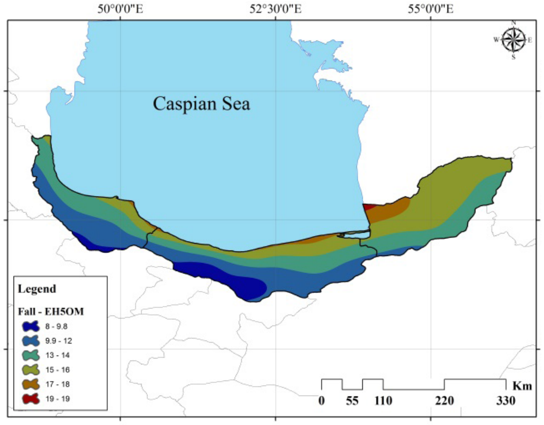

Fig 5. Zonation map of average Fall temperatures over southern Caspian Sea in years 2015 to 2050 based

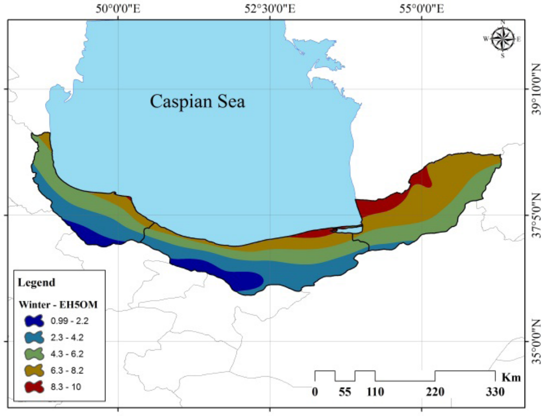

Fig 6 . Zonation map of average Winter temperatures over southern Caspian Sea in years 2015 to 2050 based

The Pearson Correlation between elevation and temperature in all seasons was at the confidence levels of 99 %. Therefore, the Pearson Correlation between elevation and temperature in all seasons was significant. According to Tab. 1, the elevation shows the highest correlation with autumn season temperature especially in the month October.

Annual	Winter	Sprig	Summer	Fall	Jan
-.694**	-.744**	-.516**	-.606**	-.759**	-.746**
Feb	Mar	Apr	May	Jun	july
-.743**	-.698**	-.593**	-.508**	-.436**	-.486**
Augh	Sep	Oct	Nov	Dec	-
-.607**	-.701**	-.759**	-.741**	-.731**	

Tab 1. Pearson Correlation between elevation and temperature
**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

CDD

Based on the findings, the lowest Annual energy consumption for Cooling would take place in the south Gilan province and so west and south Mazandaran province with 177-319 degree-days; while the highest energy consumption would be observed in the regions have low elevation, such as the northeastern Golestan province with 802-987 degree-days (Fig.7). The CDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Tab.2). The CDD values are negatively related to elevation and positively related to longitude and latitude.

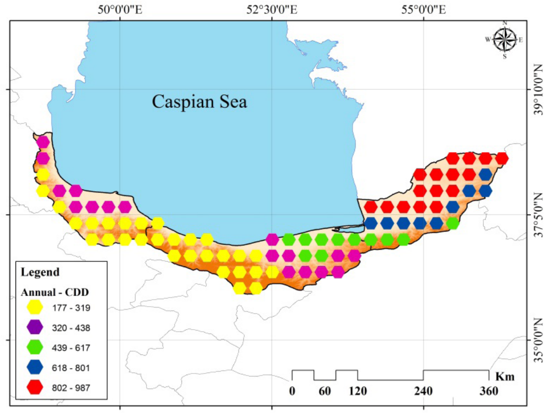

Fig 7. Spatial distributions of Annual Cooling degree-days CDD

Fig. 8 shows that in season spring, the highest CDD values are observed in the northeastern corner of the Golestan province with 54-70 degree-days, while the **lowest** are observed in the coastal southern Caspian Sea (SCS) (north Mazandaran province with 3-14 degree-days). The CDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (tab. 2). The CDD values are negatively related to elevation and positively related to longitude and latitude. Fig. 9 shows that in season Summer, the highest CDD values (217-249) are observed in the northeastern corner of the Golestan province, while the **lowest** are observed in the coastal southern Caspian Sea (SCS) (west and south Mazandaran province with 80-108 degree-days). The CDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (tab. 2). The CDD values are negatively related to elevation and positively related to longitude and latitude. Fig. 10 shows that in season Fall, **the highest** CDD values (24-30 degree-days) are observed in the northeastern corner of the Golestan province, while the **lowest** are observed in the coastal southern Caspian Sea (SCS) (south Gilan province, west and south Mazandaran province With 4-7 degree-days). The CDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (tab. 2). The CDD values are negatively related to elevation and positively related to longitude and latitude. The highest value positive (negative) Correlation is significant at the 0.01 level (0.625) between CDD and elevation in season fall is occurred. But in season winter energy consumption for Cooling is in case study 0 degree-days (Fig.11).

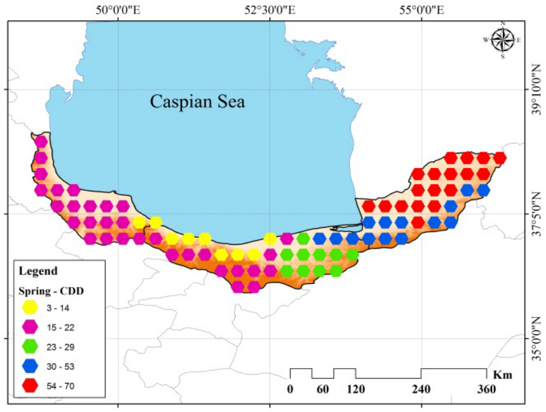

Fig 8. Spatial distributions of Spring Cooling degree-days CDD

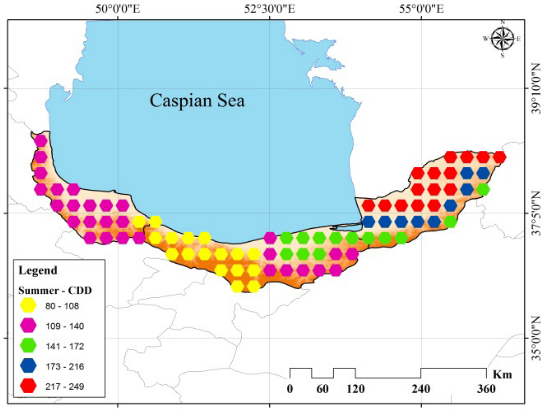

Fig 9. Spatial distributions of Summer Cooling degree-days CDD

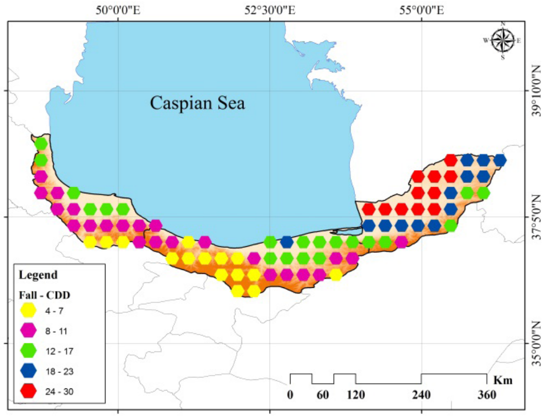

Fig 10. Spatial distributions of Fall Cooling degree-days CDD

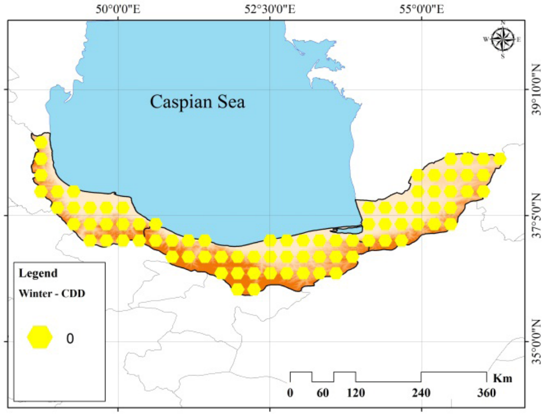

Fig 11. Spatial distributions of winter Cooling degree-days HDD

HDD

The HDD maps Annual (Fig. 12), spring (Fig. 13), summer (Fig. 14), fall (Fig. 15) and winter (Fig. 16) are generated and their spatial distributions are presented. The highest Annual HDD amounts (2601-2893 degree-days) are observed in the south region of the Gilan and Mazandaran province. This region is located by the high altitudes of Alborz Mountain range. The HDD are highest in the Alborz Mountains range and tend to decrease in the east towards the Golestan province. Fig. 12 also shows that, the **lowest** Annual HDD amounts (1340-1726 degree-days) are observed in the northwestern corner of the Golestan province and eastern shores Mazandaran province. The patterns of HDD are relatively parallel to Caspian Sea coast (CSC). These values increase when we go towards the south-western and reach more than 2600 degree-days. Therefore, there would be greater energy needs in the Heating period for the regions in the central areas than those regions located in Alborz Mountain range regions. The HDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Tab. 2). The HDD values are positively related to elevation and negatively related to longitude and latitude.

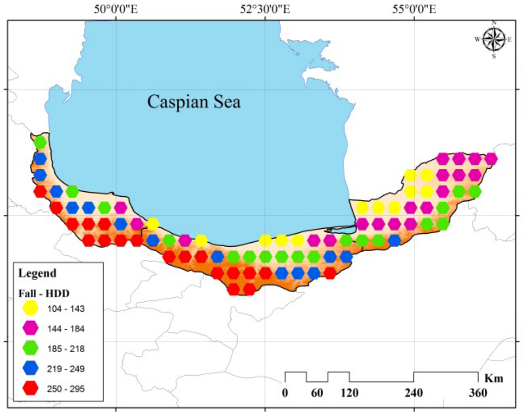

Fig 12. Spatial distributions of Annual Heating degree-days HDD

Fig. 13 shows that in season spring, the highest HDD values (117-145 degree-days) are located in the south region of the Gilan and Mazandaran province (Alborz Mountain range); Also the lowest season spring HDD amounts (29-42 degree-days) are observed in the northwestern corner of the Golestan province. The HDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Tab. 2). The HDD values are positively related to elevation and negatively related to longitude and latitude. The highest value negative Correlation is significant at the 0.01 level (0.786) between HDD and longitude in season spring is occurred. Fig. 14 shows that in season summer, the highest HDD values (6-8 degree-days) are located in the south region of the Mazandaran province (Alborz Mountain range); Also the lowest in season summer HDD amounts (0-3 degree-days) are observed in the Golestan province and east Mazandaran province. The HDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Tab. 2). The HDD values are positively related to elevation and negatively related to longitude and latitude. Only in season summer was not Correlation significant at the 0.01 level (-0.216) between HDD and latitude.

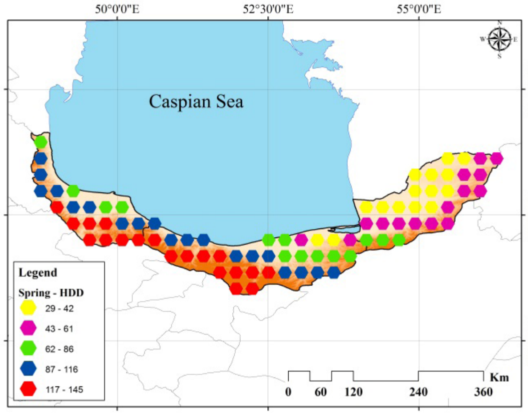

Fig 13. Spatial distributions of Spring heating degree-days CDD

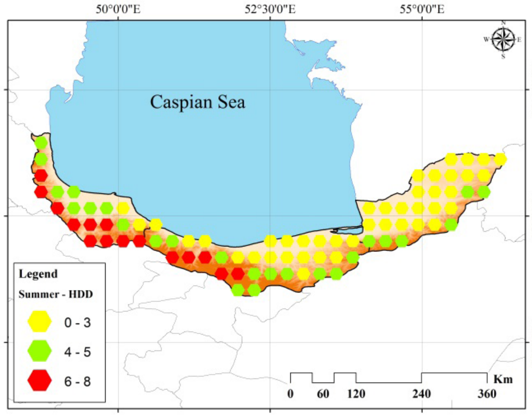

Fig 14. Spatial distributions of Summer Heating degree-days HDD

Fig. 15 shows that in season Fall, the highest HDD values (250-295 degree-days) are located in the south region of the Gilan and Mazandaran province (Alborz Mountain range); Also the lowest in season Fall HDD amounts (104-143 degree-days) are observed in the northwestern corner of the Golestan province and eastern shores Mazandaran province. The HDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Ttab. 2). The HDD values are positively related to elevation and negatively related to longitude and latitude. Fig. 16 shows that in season winter, the highest HDD values (543-585 degree-days) are located in the south region of the Gilan and Mazandaran province

(Alborz Mountain range); Also the lowest in season winter HDD amounts (341-407 degree-days) are observed in the northwestern corner of the Golestan province. The HDD data are analyzed by using as Pearson Correlation between elevation, latitude and longitude (Tab. 2). The HDD values are positively related to elevation and negatively related to longitude and latitude. **The highest** value negative Correlation is significant at the 0.01 level (0.578) between HDD and latitude in season winter is occurred.

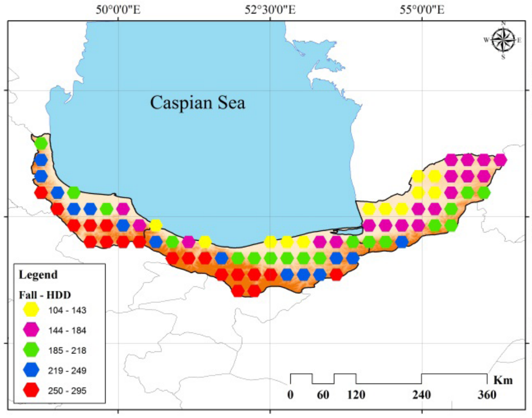

Fig 15. Spatial distributions of Fall heating degree-days HDD

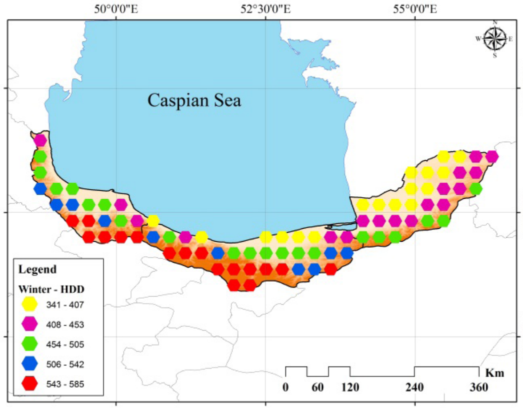

Fig 16. Spatial distributions of Winter heating degree-days HDD

In this research in order to take into consideration the impact of the geographical conditions such as elevation, latitude and longitude on the HDD & CDD values, the Pearson Correlation method was used. The results show that the value of the CDD decreases with elevation and the results show that the value of the HDD increases with elevation (tab. 2). Maximum relation of HDD versus elevation with a correlation coefficient of R = 0.753 and a coefficient of determination of R^2 = 0.567 in Annual, HDD versus latitude with a correlation coefficient of R = -0.578 and a coefficient of determination of R^2 = 0.334 in season winter and HDD versus longitude with a correlation coefficient of R = -0.786 and a coefficient of determination of R^2 = 0.617 in season spring has occurred. Also Maximum relation of CDD versus elevation with a correlation coefficient of R = -0.625 and a coefficient of determination of R^2 = 0.39 in season fall, CDD versus latitude with a correlation coefficient of R = 0.628 and a coefficient of determination of R^2 = 0.394 in season fall and CDD versus longitude with a correlation coefficient of R = 0.834 and a coefficient of determination of R^2 = 0.695 in season spring has occurred.

Par	longitude	latitude	Elevation	CDD					HDD				
				Spring	Summer	Fall	Winter	Annual	Spring	Summer	Fall	Winter	Annual
Lon	1	0.177	-.229*	.834**	.781**	.688**	.a	.807**	-.786**	-.592**	-.548**	-.517**	-.534**
Lat	0.177	1	-.438**	.547**	.600**	.628**	.a	.614**	-.531**	-0.216	-.490**	-.578**	-.534**
Elev	-.229*	-.438**	1	-.348**	-.512**	-.625**	.a	-.490**	.587**	.688**	.722**	.741**	.753**

Tab 2. Pearson Correlation between CDD & HDD with elevation, longitude and latitude
**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level
a. Cannot be computed because at least one of the variables is constant.

CONCLUSION

In this study, an analysis of heating and cooling degree-day data also air temperatures values for 83 cells in southern Caspian Sea (CS) was performed based on annual and seasonal simulated air temperature data Model EH5OM, covering a period of 35 years (2015–2050). Also The HDD and CDD are analyzed by using Pearson Correlation between elevation, latitude and longitude.

The lower annual average air temperatures values are recorded for the mountainous regions; areas where is located by the high altitudes of Alborz Mountain range; and so the higher annual average air temperatures values are recorded at the northwestern corner of the Golestan province parts; areas where the in the regions have low elevation.

The highest Annual HDD are observed in the south region of the Gilan and Mazandaran province and high altitudes of the Alborz Mountain range, while the lowest are observed in the northwestern corner of the Golestan province and eastern shores Mazandaran province.

Heating degree-day values are negatively related to longitude and latitude, while positively related to altitude. The effect of altitude is significant. Altitude is determined to be the most effective in annual and seasonal the heating degree-day distributions.

Highest annual CDD is observed in the northeastern Golestan province; in the regions have low elevation. The cooling degree-day values are negatively related to altitude while positively related to longitude and latitude. The effects of latitude and longitude on cooling degree-day distribution are all significant. Longitude is determined to be the most effective. Therefore, there would be greater energy needs in the cooling period for the regions in the northern and eastern located in Golestan province.

Results indicate there was a fairly significant and inverse relationship between HDD and CDD in CS.

The annual HDD values for this climatic zone (CS) are much higher than the annual CDD values, which imply that energy consumption for heating load will be much higher than the cooling load for this region; which imply that the energy consumption for heating load will be higher than the cooling load for this region.

The results can be used in the estimation of the energy consumption in residential, commercial and industrial building in southern Caspian Sea (CS).

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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