JAET

Journal homepage: http://jae-tech.com

Journal of Applied Engineering & Technology

ISSN: 2523-6032 ISSN-L : 2523-2924

# Forecasting Energy Consumption Using Calculation of CDDs in Pakistan Using Two Different Methods

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DOI: https://doi.org/10.55447/jaet.06.02.68

**Abstract:** Energy consumption has increased due to industrialization and other factors involved which gives the researchers to ponder upon the methods to set policy and forecast the need of energy in coming days. Pakistan with different cities comprising of various climatic zones, this study shown the highest CDDs in city of Hyderabad among large cities with high population flux and then followed by Karachi with 2nd highest CDDs among the mentioned cities with highest population and thus huge consumption of power, Quetta having lowest CDDs among the cities due to highland and cold climatic region. Pakistan location is affected by the GHGs aftermath is floods and different natural catastrophe as mentioned by UN because it is surrounded one of largest emitters of $CO_2$ and Pakistan is 17th Largest emitter of GHGs. These natural catastrophes can be due to coal power projects emissions that are increasing day by day and effecting the local climate of Pakistan, but the neighboring countries emissions is also affecting the climate of Pakistan. There are two methods discussed in this paper and their results and validation are thus observed. The two methods are ASHRAEs method and Hitchens's method. The aim is to calculate the CDDs of major cities or provincial capitals of Pakistan. The study will help policy makers to plan the power projects accordingly by considering the degree days in major cities of Pakistan. In this research climatic regions of the country were studied with the average temperatures taken for the calculation of CDDs of major cities of Pakistan and their data was procured from meteorological department of Pakistan to study the CDDs of the few cities. This is mostly used for prediction of monthly degree days using Hitchens's method for month of year and can be conveyed to power generation and distribution companies. Hitchens's method and ASHRAE were used, and it validated the calculation for every mentioned city in Pakistan. Due to simplicity ASHRAE came out as simple and balanced one and authenticated by most researchers worldwide.

**Keywords:** Energy Consumption and Degree days, Degree Days, Methods for CDDs, Degree Days in Pakistan.

## 1. Introduction

It has been observed that, there are many methods to calculate the energy consumption of any location it can be office building, home, gymnasium, and many other structures but these all must

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be simulated and observed under such conditions to make energy efficient buildings and it is the important tool in Energy management systems[1], [2]. Pakistan being a country located on great land mass north of tropic of cancer is affected by the GHGs aftermath is floods and different natural catastrophe as mentioned by UN because it is surrounded by two, one of largest emitters of $CO_2$ and Pakistan is 17$^{th}$ Largest emitter of GHGs[3]. Salahuddin and Go revealed a long-term positive and significant relationship between energy consumption and $CO_2$ emissions[4], as well as between economic growth and energy consumption in both the short and long term[5].These natural catastrophes can be due to coal power projects emissions that are increasing day by day and effecting the local climate of Pakistan, but the neighboring countries emissions is also affecting the climate of Pakistan. There are two methods discussed in this paper and their results and validation are thus observed. The two methods are ASHRAEs method and Hitchens's method aimed to calculate the CDDs of major cities or provincial capitals of Pakistan. Base temperature would be taken as 24ºC as it is mostly considered as thermally accepted world-wide. The study will help policy makers to plan the power projects accordingly by considering the degree days in major cities of Pakistan, as Pakistan is on the verge of economic downfall and low foreign exchange reserves that can shake the economy if more projects are signed without proper studies on ground. Heating Degree Days (HDD) and Cooling Degree Days (CDD), are separate values and are specific to a particular geographic location[2,3 ][8]. Many software's are available on internet to study energy consumption.

The aim to study CDD is to forecast the energy consumption which will be consumed in Pakistan and comparison of two methods ASHRAE and Hitchins.

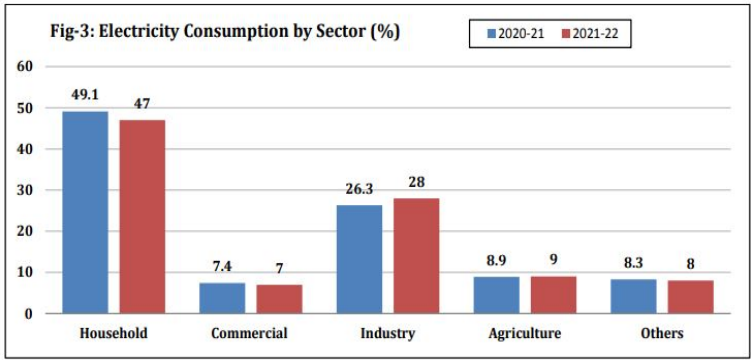



**Fig. 1 - Sector wise consumption of electricity in Pakistan (Source: Economic Survey of Pakistan)**

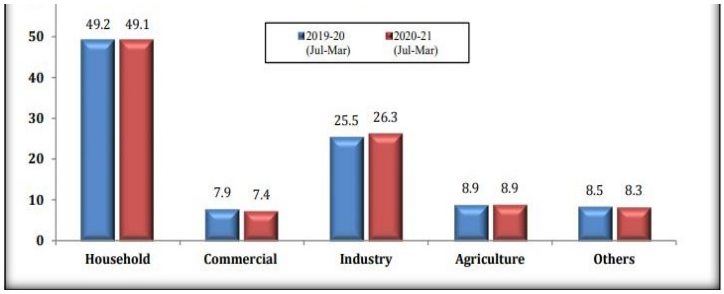



**Fig. 2 - Sector wise consumption of electricity in Pakistan[6]**

As it can be seen from the figure 2 that in 2019 and in 2020 that buildings in Pakistan consume more than 60% of total electricity mostly by household and commercial sector in the country is shown in data by Economic Survey of Pakistan from the past. And 2021-22 from Fig 1 it can be seen that consumption of house hold and commercial is decreased because of high electricity prices in country thus the usage is decreasing day by day and economic situation also the NEPRA does

not give any subsidy to off peak hours during the course of these years, where in Saudi Arabia the same consumption is increasing year by year the factor is the use of air conditioning is increased in Saudi Arabia[9] due to low cost of electricity and oil producing country, but as Pakistan relies heavily on imported oil[9]. Pakistan is 35$^{th}$ largest electricity consuming country[10].Energy consumption is often exacerbated by poor energy utilization/ consumption and building design practices[2]. Hence degree days data is very useful in analyzing energy needed to heat or cool the facility[11, 12]. Therefore, achieving energy conservation is very important at all levels for Pakistan from consumer to supplier and generation of power. It is very important to reduce the demand of oil for heating and cooling buildings. Therefore, an accurate estimate of cooling and heating energy requirements is a very important step towards this goal. So, for this purpose concept of degree day and such cooling degree day will be calculated by above mentioned methods. Researchers attempted to compare the degree days got through different methods[13, 14] available for this purpose two methods will be used in this to say which is approximately accurate. To obtain CDDs of different cities of Pakistan and analyze them using two different methods and comparison of results for different cities of Pakistan at base temperature of 24$^0$C and showing relation, trends and similarities in different months cooling degree days and validate the methods for different cities of Pakistan.

### 1.1 Problem statement

Like all low middle socio-economic countries, Pakistan is also facing energy crisis and moving towards modern building structures and high urbanization due to shift of population from rural to urban areas as a natural trend and high UHI urban heat island effect so there is need to study CDDs to ensure balanced supply and demand and policy planning for power plants installation. To cope up the requirement and planning of energy and energy projects all stakeholders of country including policy makers need to ponder upon the evolving methods of calculating energy consumption in line with demand and for energy management system. Therefore, two methods are used in this study to calculate cooling degree days of different cities of Pakistan as mostly in summer season there is need of space cooling using air conditioner in Pakistan so CDDs are calculated in this regard and to validate the study through two methods comparison.

## 2. Background and Literature Review

Energy consumption is the most important in present era due to increased modernization, industrialization and other factors which has compelled all the stakeholders including researchers to ponder upon the methods to set policy and forecast the need of energy in coming days according to weather pattern which sets cooling degree days. These degree days are further used to get power consumption or energy required in the particular area, town, building, room, gymnasium using particular software for finding energy transfer which is then used to find the energy consumption of any facility mentioned above[15, 16]. So in this regard for simplicity the hitchins proposed formula to calculate the monthly cooling degree days [17].

### 2.1 Heating degree days & Cooling degree days (HDD & CDD)

Degree day is basically a measure of heating and cooling. Degree day is the simplest unit used to measure heating and cooling requirements of a building by utilizing the outside air temperature data. Degree day method is the easiest way of calculating energy requirements. This makes degree days very useful for energy as compared to other methods of estimating energy demand. A degree day is calculated as a function of time that varies with temperature. Basically, degree days are defined as the number of degrees by which the average daily temperature is higher than 24˚C i.e. (Cooling degree days) or lower than 18˚C i.e. (Heating degree days). More importantly degree days are very helpful to estimate air conditioning usage in summer season and heating usage in winter

season. By using degree days, we can easily determine how much power is required for air conditioning in summer season to achieve thermal comfort and how much power is required by heating equipment's to achieve thermal comfort in winter season. Therefore, degree days method is one of the well-known and simplest method used in the heating, ventilating and air conditioning industries to estimate the heating and cooling energy requirements[11], [17–20].
Degree days are classified as follows:
A zero-degree day in energy management is when either heating or cooling consumption is at a minimum, which is useful with power utility companies in predicting seasonal low points in energy demand. Heating degree days (HDD) is used to measure heating demand of a building which depends upon outside air temperature.
Both are directly proportional to each other. Heating degree days are those days in which we need heating to achieve thermal comfort. Heating degree days are indicative of-the need to heat buildings[22]. Heating degree day is mainly defined as the number of degrees by which average daily temperature is lower than 18˚C. Heating degree days depend upon the base temperature i.e., the outside temperature below which the building needs heating.
Cooling degree day (CDD) is used to measure the cooling demand of a building. It also depends upon the base temperature i.e., the outside temperature above which building needs cooling. Cooling degree days are mainly defined as the number of degrees by which the average daily temperature is higher than 24˚C. Cooling degree days are used to quantify the cooling requirement of buildings. Cooling degree days are the days in which we need cooling to maintain thermal comfort[23].

### 2.2 Importance of CDD and HDD worldwide

Heating and cooling degree days are very significant in estimating energy necessity for heating and cooling of a building to achieve thermal comfort. By considering heating and cooling degree days for different countries in proportion to their weather their energy demand can be estimated. This is the simplest and most powerful technique which is being used worldwide. For example, those countries which are colder such as European countries where temperature remains lower than the base temperature i.e., 18˚C, heating degree days will play important role in estimating the heating energy demand easily.
Apart from that considering middle east countries where usually temperature remains higher than the base temperature i.e., 24˚C. Cooling-degree-days will be helpful in estimating cooling energy requirements. Degree days also provide information about duration of energy demand. The summation of total degree days for a month and/or annually is used in estimating the amount of heating and cooling required for a building. It provides information on energy consumption and how to mitigate the energy demand. As far as energy requirement for cooling and heating of building is concerned, HDD and CDD are effective methods of reducing excess energy demand. The sensible usage of energy along with better management of environmental problems related with energy consumption results in cost reduction and maximized benefits/comforts for society. By properly considering the Heating and Cooling degree days for a specific region we can avoid the excess energy requirement which will result in energy efficient building and constructions. Ultimately by supplying the correct amount of energy heating and cooling costs will be reduced to a greater extent. So, HDD and CDD has its own significance for energy management and its cost related issues worldwide[21–23].

### 2.3 Impact of CDD and HDD on energy consumption

HDDs and CDDs are used as a parameter to quantify the heating and cooling demand of a building. The greater the number of heating degree days, the higher will be the heating requirement. This implies that more energy will be required by heating equipment's to raise the temperature up to thermal comfort. Likewise, the greater the cooling degree days more energy will be required by

cooling equipment's to drop the temperature up to thermal comfort. This is how HDD and CDD impacts on energy consumption. Furthermore, increase in heating or cooling degree days will ultimately enhance the demand of energy equipment's usage which will result in more power consumption and will lead to increase in cost of bills of electricity due to the greater demand of heating and cooling energy equipment's for heating or cooling purpose. Therefore, by carefully estimating the heating and cooling degree days we can calculate the appropriate amount of energy needed for heating and cooling of a building. In doing so the correct amount of energy will be supplied and there will be reduction of energy wastage that is favorable. Along with that cost of electricity bills can also be reduced by utilizing proper amount of energy[8], [13], [24].

## 3. Research Methodology

In this work first the climatic regions of the country were studied with the average temperatures of major cities of Pakistan and their data was procured from meteorological department to study the CDDs of the cities mentioned.

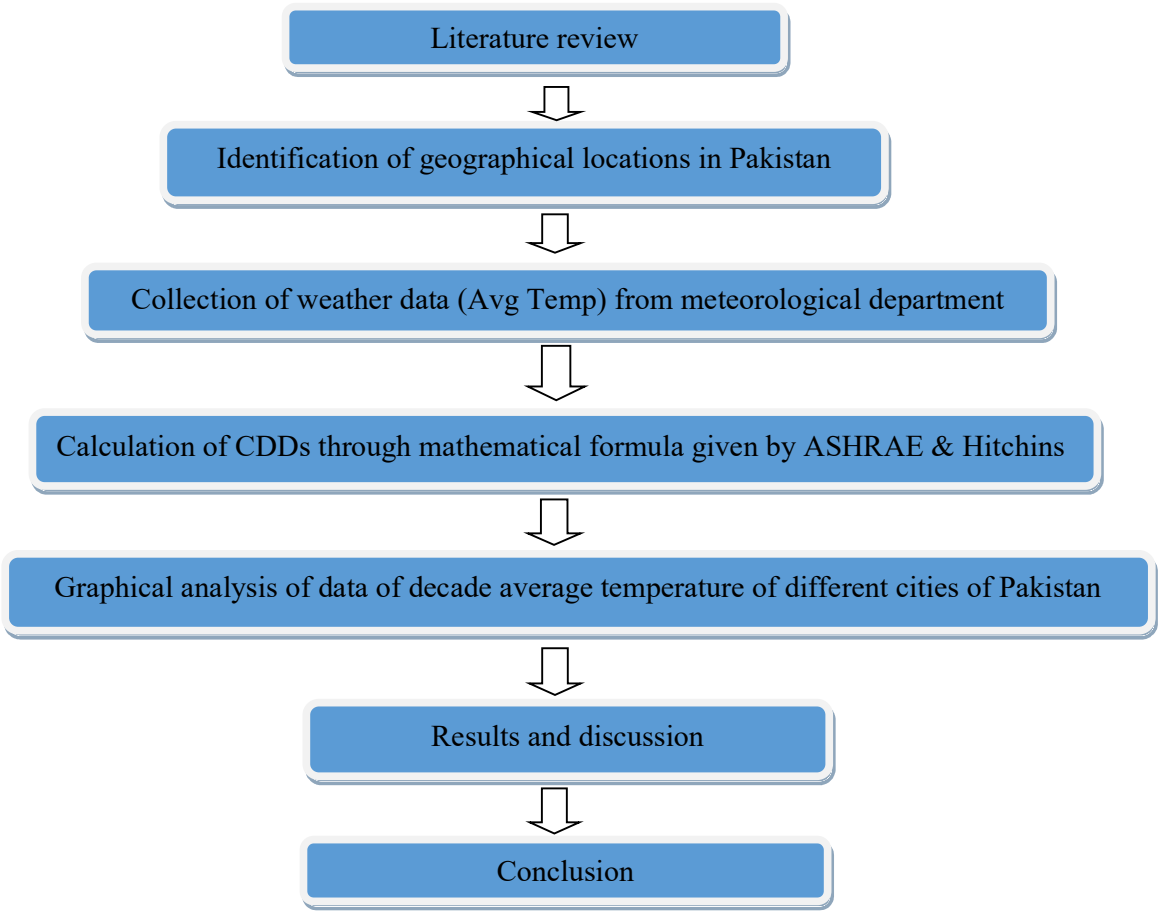



**Fig. 3 – Flow chart of research methodology**

### 3.1 Climates of Pakistan

Pakistan is divided in 4 climatic zones namely: a. highland climate b. lowland climate c. coastal Climate d. arid climate[26], [27]Pakistan is from 0 to 8000 meters high and has hence variations in temperature so for designing the power plan therefore, it is needed to see the degree days of particular location and exploit the local resource of generation and reducing the commissioning of oil based, conventional and non-renewable based power projects. In this research the temperature

data and weather data is taken from NOAA[28] and Pakistan meteorological department and 10 year data is used of Different cities of Pakistan like: Karachi, Hyderabad, Lahore, Islamabad, Peshawar and Quetta is taken for study of CDD and with different methods such as ASHRAE and Hitchins method [17]. Only 2021 data of average temperature has been done on 6 major cities of Pakistan for the calculation of CDDs of these cities with Hitchens's method and by ASHRAE, 10 years CDDs has been calculated. The data has been analyzed in SPSS Software version 22.0. The base temperature taken here is $24^0$C.

### 3.2 Methods to Calculate CDDs

The degree-day value numerically represents relatively warm or cold weather over a specified period, such as days, months, or a year. This is useful for tracking fuel budgets or reducing the performance of various buildings to a general account for comparison. It can be estimated the amount of savings due to energy saving measures considering the changing weather. There are several evaluation methods such as degree day in literature[9] but this will follow the below mentioned methods for the study.

### 3.3 American Society of Heating, Refrigerating and air-conditioning Engineers (ASHRAE) method

It is one of the simplest methods used worldwide to calculate degree days given by ASHRAE for cooling degree days principally, it is the difference between mean daily temperature and base temperature which is taken in this paper is $24^0$C, for heating degree days it is difference between base temperature such as $18^0$C and mean daily temperature[29].
Equation for HDD

$$HDD = (T_b - T_m)^{+} \quad \ldots\ldots\ldots\ldots\ldots \quad (1) \text{[29]}$$

whereas $T_b$ stands for base temperature it may be 18, 17 ……. $T_m$ stands for average daily temperature.

And for CDD

$$CDD = (T_m - T_b)^{+} \quad \ldots\ldots\ldots\ldots\ldots \quad (2) \text{[29]}$$

Daily mean temperature is the average of daily maximum temperature $T_{max}$ and daily minimum $T_{min}$
This is given by Equation

$$T_m = \frac{(T_{max} + T_{min})}{2} \quad \ldots\ldots\ldots\ldots \quad (3) \text{[29]}$$

Although it is basic method, majority of the researchers use this method because of its simplicity and less necessity of input data.[30]

### 3.4 Hitchin's Method

Roger Hitchin's proposed the equation to calculate the monthly degree days which uses reduced data, it is same as ASHRAE method. It consists of monthly mean temperature $T_{mm}$ and standard deviation $\sigma_m$ of monthly mean temperature the monthly HDD and CDD are given by equations (4) and (6).
The suffixes m represent month and b represents the base temperature at which it is calculated

$$HDD_{mb} = \frac{N_m(T_b - T_{mm})}{1 - e^{-k(T_b - T_{mm})}} \quad \ldots\ldots\ldots\ldots \quad (4) \text{[17]}$$

Where $N_m$ is the number of days in a month and k is the location specific constant given by

$$k = \frac{2.5}{\sigma_{mm}} \text{..... (5) [17]}$$

$$CDD_{mb} = \frac{N_m(T_{mm} - T_b)}{1 - e^{-k(T_{mm} - T_b)}} \text{..... (6) [17]}$$

Errors may be seen due to inappropriate value of σ and they may increase if $T_{mm}$ and $T_b$ are close.[14], [17], [29], [31]Base temperature here will also be taken $24^0$C.[32]Calculations are done below by Hitchins method for each city mentioned.

**Table 1 - Calculation of CDDs of Hyderabad using Hitchens's method of monthly degree days calculation.**

| Month | Hyderabad | | | |
|---|---|---|---|---|
| | Average | SD | Value of k | CDD |
| Jan | 17 | 1.72 | 1.453 | 0.0083 |
| Feb | 23 | 2.69 | 0.929 | 18.27705 |
| Mar | 28 | 2.16 | 1.157 | 125.224 |
| Apr | 31 | 1.18 | 2.119 | 210.0001 |
| May | 33 | 1.05 | 2.381 | 279 |
| Jun | 33 | 0.41 | 6.098 | 270 |
| Jul | 32 | 1.19 | 2.101 | 248 |
| Aug | 31 | 0.7 | 3.571 | 217 |
| Sep | 32 | 1.61 | 1.553 | 240.001 |
| Oct | 29 | 1.62 | 1.543 | 155.0692 |
| Nov | 25 | 1.7 | 1.471 | 38.94565 |
| Dec | 19 | 2.03 | 1.232 | 0.328092 |

**Table 2 - Calculation of CDDs of Islamabad using Hitchens's method of monthly degree days calculation.**

| Month | Islamabad | | | |
|---|---|---|---|---|
| | Average | SD | Value of k | CDD |
| Jan | 11 | 1.76 | 1.42 | 0 |
| Feb | 16 | 3.28 | 0.762 | 0.505554 |
| Mar | 20 | 2.86 | 0.874 | 3.877029 |
| Apr | 23 | 3.22 | 0.776 | 25.5806 |
| May | 28 | 2.85 | 0.877 | 127.8294 |
| Jun | 31 | 3.67 | 0.681 | 211.8016 |
| Jul | 30 | 2.55 | 0.98 | 186.5213 |
| Aug | 29 | 1.94 | 1.289 | 155.2466 |
| Sep | 28 | 1.56 | 1.603 | 120.1973 |
| Oct | 23 | 3.33 | 0.751 | 27.70038 |
| Nov | 16 | 1.86 | 1.344 | 0.005137 |
| Dec | 11 | 2.31 | 1.082 | 0.000314 |

**Table 3 - Calculation of CDDs of Karachi using Hitchens's method of monthly degree days calculation.**

| Month | Karachi | | | |
|---|---|---|---|---|
| | verage | SD | Value of k | CDD |
| Jan | 18 | 1.75 | 1.429 | 0.0352 |
| Feb | 23 | 2.31 | 1.082 | 14.35474 |
| Mar | 28 | 1.69 | 1.479 | 124.3352 |
| Apr | 31 | 1.26 | 1.984 | 210.0002 |
| May | 32 | 1.55 | 1.613 | 248.0006 |
| Jun | 32 | 0.38 | 6.579 | 240 |
| Jul | 31 | 1.48 | 1.689 | 217.0016 |
| Aug | 29 | 0.81 | 3.086 | 155 |
| Sep | 31 | 1.7 | 1.471 | 210.0071 |
| Oct | 28 | 1.06 | 2.358 | 124.0099 |
| Nov | 25 | 1.49 | 1.678 | 36.88889 |
| Dec | 21 | 2.26 | 1.106 | 3.495572 |

**Table 4 - Calculation of CDDs of Lahore using Hitchens's method of monthly degree days calculation.**

| Month | Lahore | | | |
|---|---|---|---|---|
| | Average | SD | Value of k | CDD |
| Jan | 12 | 1.98 | 1.263 | 0.0001 |
| Feb | 18 | 2.78 | 0.899 | 0.766836 |
| Mar | 23 | 1.9 | 1.316 | 11.36165 |
| Apr | 26 | 3.4 | 0.735 | 77.91454 |
| May | 31 | 2.81 | 0.89 | 217.4282 |
| Jun | 33 | 3.07 | 0.814 | 270.1778 |
| Jul | 32 | 3.07 | 0.814 | 248.369 |
| Aug | 31 | 1.61 | 1.553 | 217.0041 |
| Sep | 29 | 2.25 | 1.111 | 150.5825 |
| Oct | 26 | 3.18 | 0.786 | 78.24623 |
| Nov | 19 | 1.79 | 1.397 | 0.138978 |
| Dec | 14 | 2.14 | 1.168 | 0.002623 |

**Table 5 - Calculation of CDDs of Peshawar using Hitchens's method of monthly degree days calculation.**

| Month | Peshawar | | | |
|---|---|---|---|---|
| | Average | SD | Value of k | CDD |
| Jan | 12 | 0.93 | 2.688 | 0 |
| Feb | 16 | 2.52 | 0.992 | 0.080139 |
| Mar | 20 | 2.13 | 1.174 | 1.14277 |
| Apr | 24 | 3.4 | 0.735 | 0 |
| May | 29 | 2.4 | 1.042 | 155.8512 |
| Jun | 31 | 2.56 | 0.977 | 210.2252 |
| Jul | 31 | 3.37 | 0.742 | 218.211 |
| Aug | 31 | 2.33 | 1.073 | 217.1188 |
| Sep | 30 | 1.58 | 1.582 | 180.0136 |
| Oct | 23 | 3.68 | 0.679 | 31.89613 |
| Nov | 16 | 2.53 | 0.988 | 0.088656 |
| Dec | 10 | 1.73 | 1.445 | 0 |

**Table 6 - Calculation of CDDs of Quetta using Hitchens's method of monthly degree days calculation.**

| Month | Quetta | | | |
|---|---|---|---|---|
| | Average | SD | Value of k | CDD |
| Jan | 3 | 3.82 | 0.654 | 0.0007 |
| Feb | 11 | 4.05 | 0.617 | 0.11961 |
| Mar | 16 | 2.96 | 0.845 | 0.287822 |
| Apr | 20 | 2.84 | 0.88 | 3.660274 |
| May | 24 | 2.84 | 0.88 | 0 |
| Jun | 29 | 1.79 | 1.397 | 150.139 |
| Jul | 30 | 1.88 | 1.33 | 186.0637 |
| Aug | 28 | 1.35 | 1.852 | 124.0752 |
| Sep | 26 | 1.59 | 1.572 | 62.70313 |
| Oct | 17 | 3.42 | 0.731 | 1.308537 |
| Nov | 11 | 2.57 | 0.973 | 0.001252 |
| Dec | 7 | 3.4 | 0.735 | 0.001974 |

## Degree Days Calculation of Cities in a Decade using ASHRAE method.

| Years | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER |
|---|---|---|---|---|---|---|---|---|
| 2012 | 58 | 194 | 262 | 253 | 240 | 224 | 168 | 141 |
| 2013 | 72 | 172 | 265 | 252 | 238 | 185 | 202 | 195 |
| 2014 | 56 | 176 | 269 | 291 | 248 | 222 | 191 | 166 |
| 2015 | 79 | 215 | 278 | 279 | 239 | 202 | 183 | 174 |
| 2016 | 90 | 175 | 275 | 278 | 242 | 203 | 177 | 156 |
| 2017 | 90 | 205 | 293 | 270 | 230 | 220 | 179 | 196 |
| 2018 | 132 | 210 | 319 | 263 | 238 | 194 | 171 | 186 |
| 2019 | 67 | 214 | 266 | 298 | 264 | 201 | 235 | 178 |
| 2020 | 46 | 235 | 286 | 288 | 294 | 240 | 215 | 167 |
| 2021 | 123 | 219 | 285 | 269 | 245 | 211 | 229 | 154 |

**Table 7- Degree Days Calculation of Hyderabad in a Decade**

| Year | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER |
|---|---|---|---|---|---|---|---|---|
| 2012 | 39 | 142 | 202 | 203 | 180 | 149 | 151 | 123 |
| 2013 | 57 | 125 | 206 | 242 | 190 | 155 | 172 | 164 |
| 2014 | 44 | 141 | 210 | 244 | 207 | 175 | 160 | 150 |
| 2015 | 62 | 183 | 224 | 271 | 209 | 156 | 172 | 166 |
| 2016 | 86 | 140 | 217 | 224 | 198 | 163 | 133 | 125 |
| 2017 | 57 | 158 | 227 | 234 | 182 | 172 | 153 | 157 |
| 2018 | 92 | 174 | 263 | 225 | 198 | 143 | 133 | 158 |
| 2019 | 58 | 162 | 217 | 261 | 231 | 173 | 217 | 186 |
| 2020 | 49 | 178 | 239 | 269 | 264 | 213 | 208 | 170 |
| 2021 | 117 | 201 | 263 | 245 | 219 | 168 | 215 | 137 |

**Table 8- Degree Days Calculation of Karachi in a Decade.**

| Years | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER |
|---|---|---|---|---|---|---|---|---|
| 2012 | 2 | 25 | 180 | 295 | 275 | 168 | 88 | 27 |
| 2013 | 0 | 20 | 194 | 256 | 199 | 129 | 96 | 43 |
| 2014 | 0 | 26 | 102 | 259 | 209 | 166 | 88 | 23 |
| 2015 | 0 | 26 | 138 | 185 | 158 | 159 | 107 | 36 |
| 2016 | 0 | 33 | 206 | 256 | 185 | 169 | 153 | 42 |
| 2017 | 9 | 60 | 195 | 201 | 191 | 170 | 124 | 49 |
| 2018 | 9 | 52 | 144 | 249 | 200 | 188 | 131 | 11 |
| 2019 | 0 | 57 | 189 | 242 | 209 | 176 | 138 | 25 |
| 2020 | 0 | 14 | 100 | 171 | 198 | 183 | 119 | 19 |
| 2021 | 4 | 26 | 112 | 221 | 192 | 165 | 127 | 23 |

**Table 9- Degree Days Calculation of Islamabad in a Decade.**

| Years | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER |
|---|---|---|---|---|---|---|---|---|
| 2012 | 16 | 91 | 279 | 347 | 294 | 210 | 164 | 39 |
| 2013 | 5 | 116 | 306 | 288 | 240 | 183 | 189 | 95 |
| 2014 | 1 | 65 | 226 | 342 | 271 | 247 | 150 | 58 |
| 2015 | 18 | 90 | 275 | 256 | 200 | 219 | 179 | 60 |
| 2016 | 15 | 145 | 302 | 317 | 240 | 189 | 210 | 99 |
| 2017 | 46 | 126 | 272 | 234 | 232 | 219 | 174 | 103 |
| 2018 | 30 | 115 | 268 | 265 | 212 | 245 | 169 | 56 |
| 2019 | 12 | 131 | 236 | 311 | 213 | 222 | 197 | 46 |
| 2020 | 0 | 78 | 233 | 262 | 247 | 213 | 226 | 75 |
| 2021 | 15 | 65 | 208 | 275 | 237 | 225 | 147 | 48 |

**Table 10 - Degree Days Calculation of Lahore in a Decade.**

| Years | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER |
|---|---|---|---|---|---|---|---|---|
| 2012 | 2 | 14 | 141 | 277 | 296 | 229 | 108 | 23 |
| 2013 | 0 | 12 | 177 | 260 | 252 | 192 | 154 | 52 |
| 2014 | 0 | 25 | 122 | 287 | 249 | 205 | 158 | 31 |
| 2015 | 0 | 36 | 151 | 233 | 221 | 175 | 117 | 44 |
| 2016 | 0 | 32 | 221 | 271 | 248 | 202 | 179 | 51 |
| 2017 | 6 | 85 | 219 | 248 | 229 | 205 | 130 | 50 |
| 2018 | 9 | 53 | 127 | 264 | 218 | 222 | 144 | 11 |
| 2019 | 0 | 39 | 120 | 236 | 276 | 208 | 194 | 12 |
| 2020 | 0 | 22 | 138 | 225 | 275 | 253 | 131 | 21 |
| 2021 | 2 | 46 | 156 | 210 | 218 | 217 | 176 | 32 |

**Table 11- Degree Days Calculation of Peshawar in a Decade.**

| Years | March | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|---|
| 2012 | 0 | 0 | 10 | 81 | 176 | 128 | 20 | 0 |
| 2013 | 0 | 0 | 29 | 162 | 184 | 90 | 20 | 0 |
| 2014 | 0 | 0 | 17 | 139 | 179 | 118 | 29 | 0 |
| 2015 | 0 | 2 | 40 | 126 | 156 | 129 | 4 | 0 |
| 2016 | 0 | 0 | 83 | 140 | 195 | 100 | 35 | 0 |
| 2017 | 0 | 2 | 46 | 154 | 170 | 110 | 22 | 0 |
| 2018 | 0 | 1 | 27 | 152 | 184 | 129 | 20 | 0 |
| 2019 | 0 | 0 | 10 | 101 | 189 | 119 | 46 | 0 |
| 2020 | 0 | 0 | 23 | 135 | 165 | 118 | 5 | 0 |
| 2021 | 0 | 2 | 32 | 139 | 171 | 115 | 61 | 0 |

**Table 12 - Degree Days Calculation of Quetta in a Decade.**

| City | Total Decade CDDs |
|---|---|
| HYDERABAD | 16610 |
| KARACHI | 13946 |
| PESHAWAR | 10874 |
| QUETTA | 4840 |
| LAHORE | 13724 |
| ISLAMABAD | 9416 |

**Table 13- Total Decade degree days of cities by ASHRAE method.**

| Methods | Hyderabad | Karachi | Lahore | Islamabad | Peshawar | Quetta |
|---|---|---|---|---|---|---|
| ASHRAEs | 1735 | 1565 | 1220 | 870 | 1108 | 520 |
| Hitchins | 1744 | 1528 | 1271 | 859 | 1015 | 528 |
| | | | | | | |

**Table 14- Annual Degree Days 2021 (March-Oct) by Both Methods.**

## 4. Results and Discussion

This study will help government machinery as well as policy makers to design short-term and long-term energy generation, conservation, and management plans, when to increase power plants installation or when to limit them by assessing the trend of weather of different cities in different climatic zones, launching of renewable sources can be deliberated through the study of degree days.

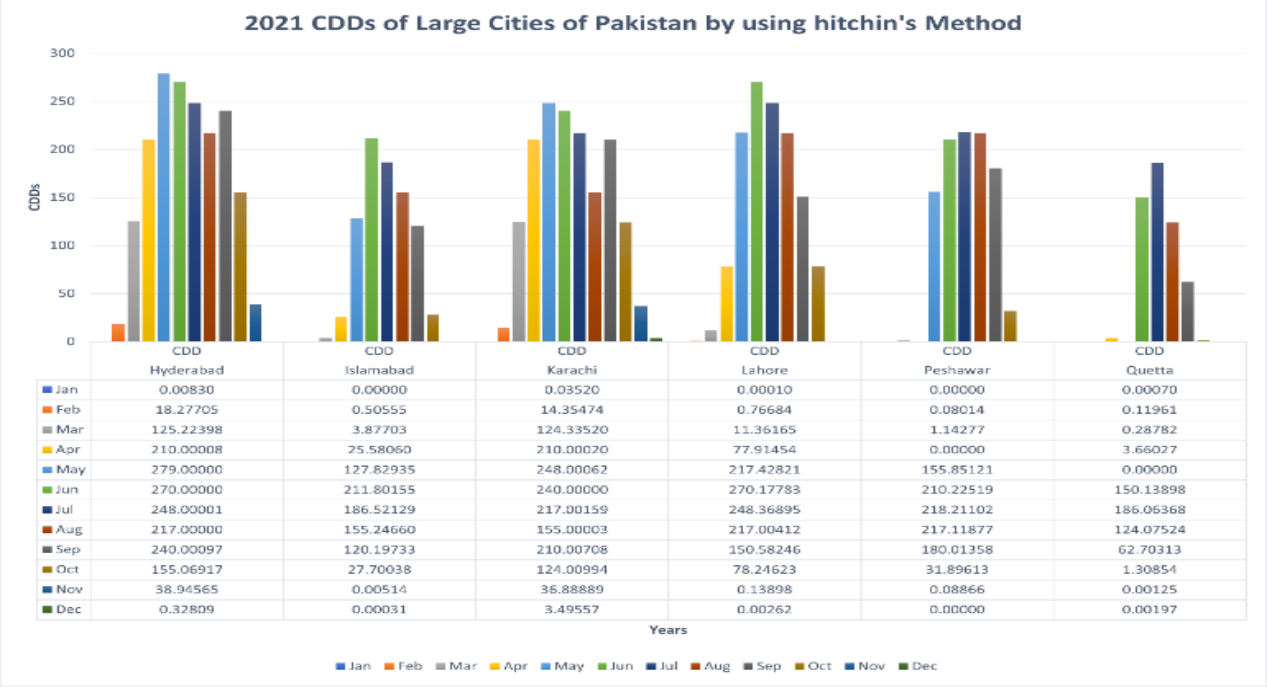
Forecasting of future degree days can be done using historical data and planning can be done accordingly. It is seen that the highest number of CDDs are in Hyderabad Sindh, it can be supposed that Hyderabad is probably the hottest among other mentioned cities in terms of CDDs and with this, its population is being increasing at high pace due to commercial, economical, and educational facilities, by such calculation and estimation of CDDs. Supply side management can be improved, and indigenous resources should be used to cater for energy crises as it can see the highest percentage of energy is consumed in residential and commercial buildings and on the consumer side, demand side management can be improved, for areas like Hyderabad the renewable source like solar PV systems might be beneficial as per their KWH cost. HESCO or other electrical distribution companies can improve its SSM by this calculation and estimation in Hyderabad. Hyderabad's temperature is highest among the other five mentioned cities of Pakistan because of its climatic location so its total sum of decade cooling degree days is 16610-degree days followed by 13946 degree days in Karachi, 13724 in Lahore, 10874 in Peshawar, 9416 in Islamabad and Quetta with least among these all having only 4840 total decade cooling degree days because it lies in highland and cold region. The highest CDD was recorded in the month of May 2018 and lowest in March 2020 in Hyderabad. Hitchens's method has almost provided the same results for Hyderabad as ASHRAE did and its validity is evident for Hyderabad and other cities as well except Peshawar because of missing data from weather station. Karachi remains 2$^{nd}$ most hot city among the mentioned group of cities and most populous so the energy consumption will be highest among all other mentioned cities as far as population is concerned. The highest CDDs recorded at base temperature 24$^0$ C in Karachi is 269-degree days in June 2020 and lowest in March 2012 and March is one of the thermally comfortable months in all years over the calculated decade, and this was obtained from the study.

All these graphs are produced using the data in tables above and are obtained through equations mentioned above.

1. In Lahore can be seen from fig. 8 that June 2012 recorded the highest sum of temperature as well as highest sum of CDDs recorded in June 2012 and lowest in March 2020.
2. In Islamabad can be seen from fig. 7 June 2012 recorded highest sum of monthly CDDs and lowest in March 2013,14,15,16,19,20.
3. In Peshawar can be seen from fig. 9 the highest CDDs recorded were in July 2012 and lowest in March 2013-20.
4. March month pattern is same for Peshawar and Islamabad can be seen from fig 7 and 9.
5. In Quetta highest CDDs were calculated in July 2016 and mostly month of march, April and October having 0 CDDs in whole decade as it is cold climate region and so in these areas heating degree days should be measured by methods given above because there is most of year pleasant weather so in these ways DISCOs and GENCOs could predict the use of energy if the pattern is common.
6. The Hitchins method gives same result as ASHRAE gave but for Peshawar its pattern is different due to missing weather data but after all both methods are good to check CDDs, but this study recommends ASHRAEs method fit because it's easy and less complicated whereas Hitchens's method involve equations and its calculation is however little bit complicated as compared with ASHRAE and is specially for a month or simply monthly CDDs calculations.
7. The values of yearly cooling degree days in table 14 for both the methods show minute difference but this difference matters some difference is due to the missing weather data and some due to mathematical error so far as hitchins method is concerned.
8. ASHRAE is very simple so gives the most approximately value than hitchins method so as in table 14 there it also shows this variation.
9. Karachi having 2$^{nd}$ highest degree days but will have highest energy consumption among the mentioned cities as far as population and industrial zone is concerned and the hottest

months will be May and June just like Hyderabad and march will have lowest CDDs as like in most of the cities and pattern is similar in each year to predict the CDDs which are then beneficial to find energy consumption can be seen in Fig 6.

10. In fig 7 it is depicted that most of the years the month of march was thermally comfortable so no CDDs in Islamabad while June remains the hot most of the years in a decade followed by July and June 2012 was hottest in Islamabad.
11. In fig. 8 it is shown that just like in Islamabad June was hot too in Lahore as month of May in Karachi and Hyderabad, and March was slightly thermally comfortable and in 2012 month of June was crossing 350 CDDs in a month and other months trend were similar like the mentioned cities.
12. In fig. 9 for Peshawar the observation is same as Islamabad; Lahore as June remain the highest CCDs month in the period of over 10 years followed by July and march remained lowest in CDDs and emerged as thermally comfortable month where the requirement of energy might be low as most of the days are thermally comfortable and that's why no need to operate air conditioners which might save the power consumption and have no any burden on power plants.
13. In fig. 10 for Quetta July remains hot followed by June and August unlike other cities which are most of the year hot and the trend remains same in every year over a decade in Quetta.
14. Fig. 11, 12, 14 shows the data of 2021 in which the sum of CDDs of cities from March-October in each city gave the same results with both the methods, whereas Peshawar due to missing weather data gives slightly different, both are used to find degree days but ASHRAE is most authenticated by researchers and easy to calculated due to easy equation.
15. In the study fig 13 shows that Hyderabad has more cooling degree days than any other mentioned city over a decade whereas Quetta was having least among the mentioned cities.
16. So, this study will help planners to plan the power generation so that there should be balance between generation and utilization which can ease the burden on foreign exchange reserves which are depleting day by day due to lack of planning and execution.




| | CDD Hyderabad | CDD Islamabad | CDD Karachi | CDD Lahore | CDD Peshawar | CDD Quetta |
|---|---|---|---|---|---|---|
| Jan | 0.00830 | 0.00000 | 0.03520 | 0.00010 | 0.00000 | 0.00070 |
| Feb | 18.27705 | 0.50555 | 14.35474 | 0.76684 | 0.08014 | 0.11961 |
| Mar | 125.22398 | 3.87703 | 124.33520 | 11.36165 | 1.14277 | 0.28782 |
| Apr | 210.00008 | 25.58060 | 210.00020 | 77.91454 | 0.00000 | 3.66027 |
| May | 279.00000 | 127.82935 | 248.00062 | 217.42821 | 155.85121 | 0.00000 |
| Jun | 270.00000 | 211.80155 | 240.00000 | 270.17783 | 210.22519 | 150.13898 |
| Jul | 248.00001 | 186.52129 | 217.00159 | 248.36895 | 218.21102 | 186.05368 |
| Aug | 217.00000 | 155.24660 | 155.00003 | 217.00412 | 217.11877 | 124.07524 |
| Sep | 240.00097 | 120.19733 | 210.00708 | 150.58246 | 180.01358 | 62.70313 |
| Oct | 155.06917 | 27.70038 | 124.00994 | 78.24623 | 31.89613 | 1.30854 |
| Nov | 38.94565 | 0.00514 | 36.88889 | 0.13898 | 0.08866 | 0.00125 |
| Dec | 0.32809 | 0.00031 | 3.49557 | 0.00262 | 0.00000 | 0.00197 |

**Fig. 4 - 2021 CDDs of large cities of Pakistan by using hitchins Method.**

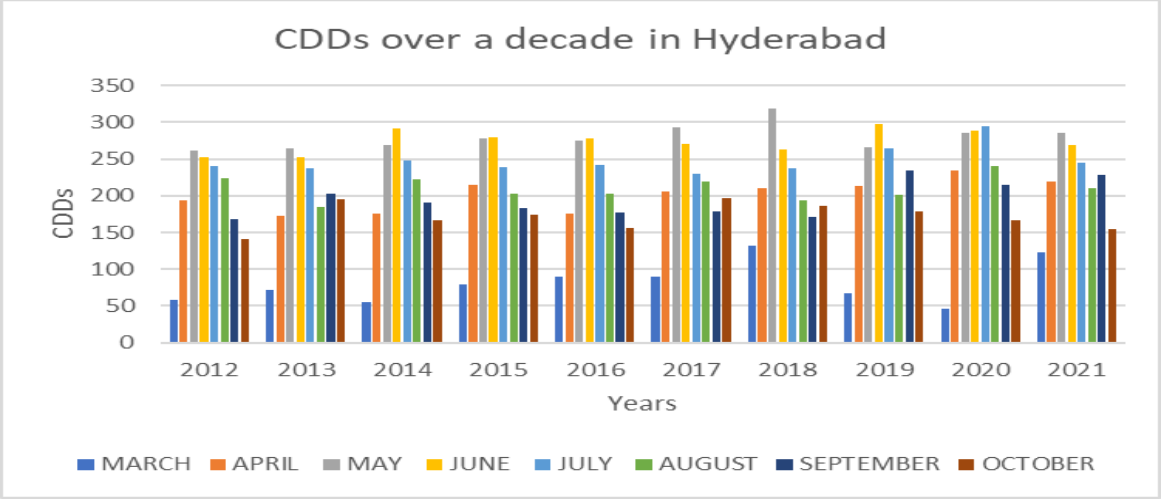



**Fig. 5 - CDDs over a decade in Hyderabad by ASHRAE method**

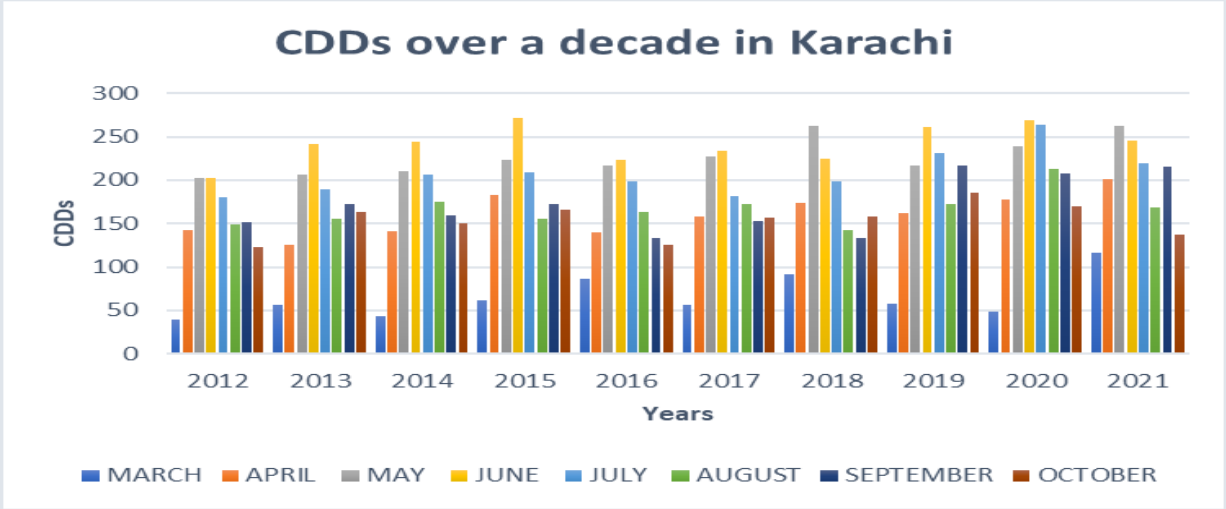



**Fig. 6-CDDs over a decade in Karachi by ASHRAE method**

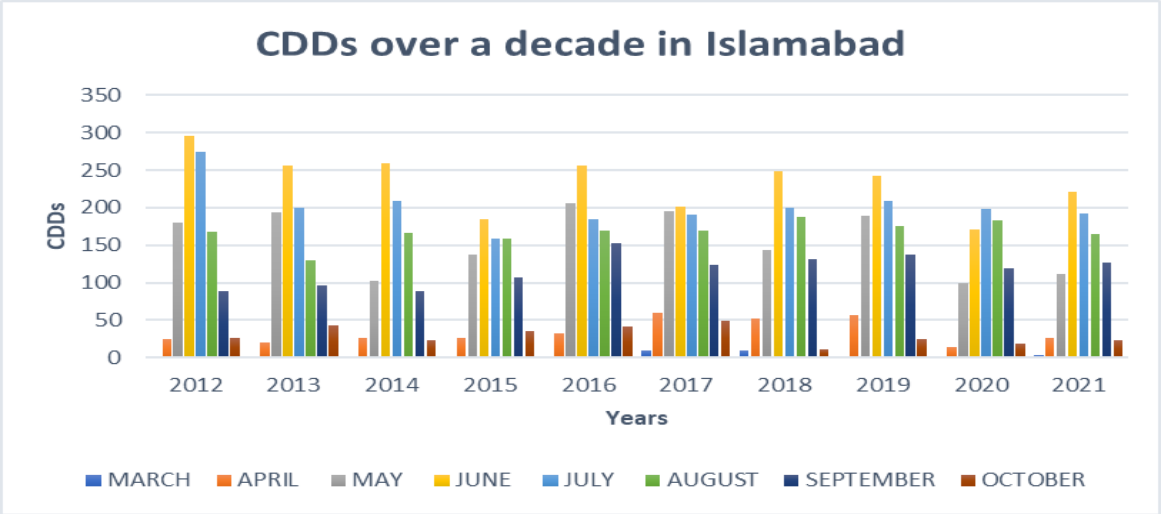



**Fig. 7- CDDs over a decade in Islamabad by ASHRAE method**

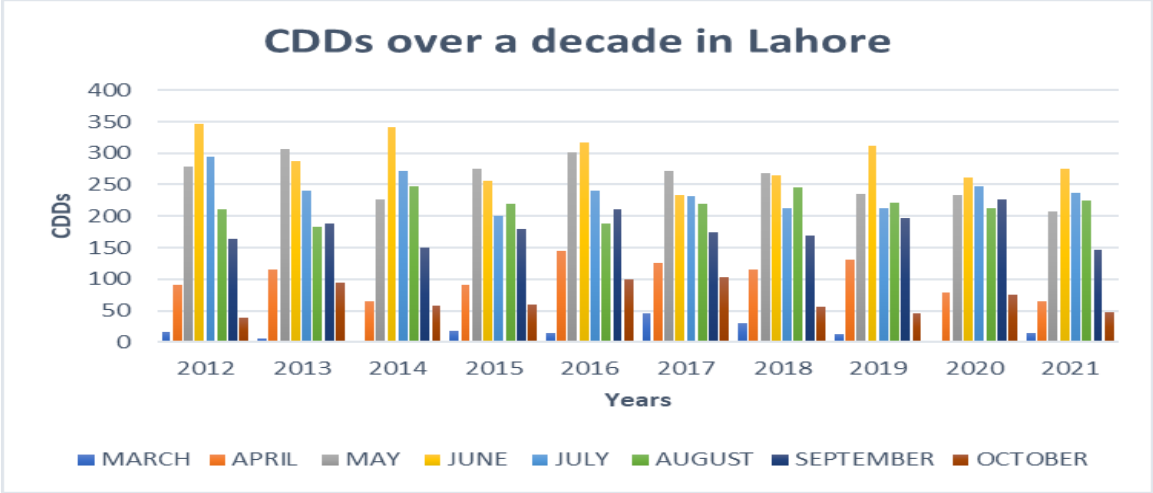



**Fig. 8- CDDs over a decade in Lahore by ASHRAE method**

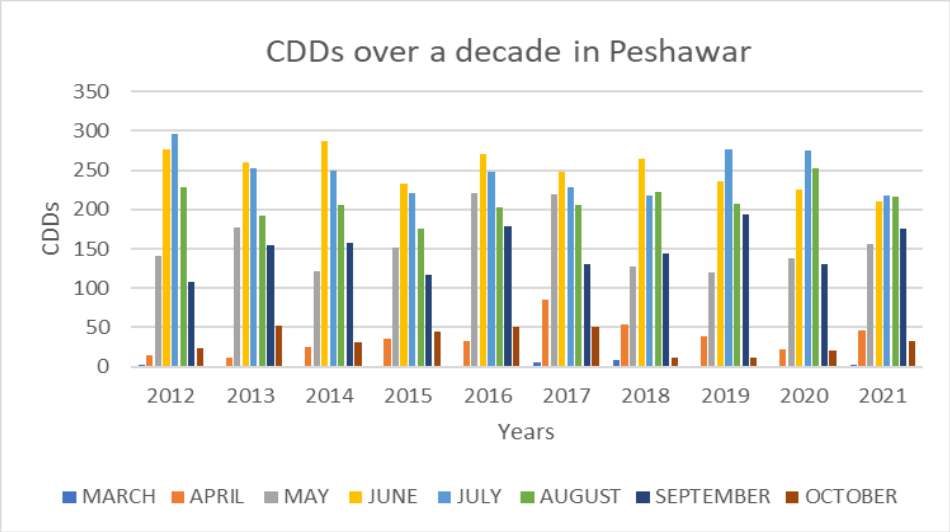



**Fig: 9 - CDDs over a decade in Peshawar by ASHRAE method**

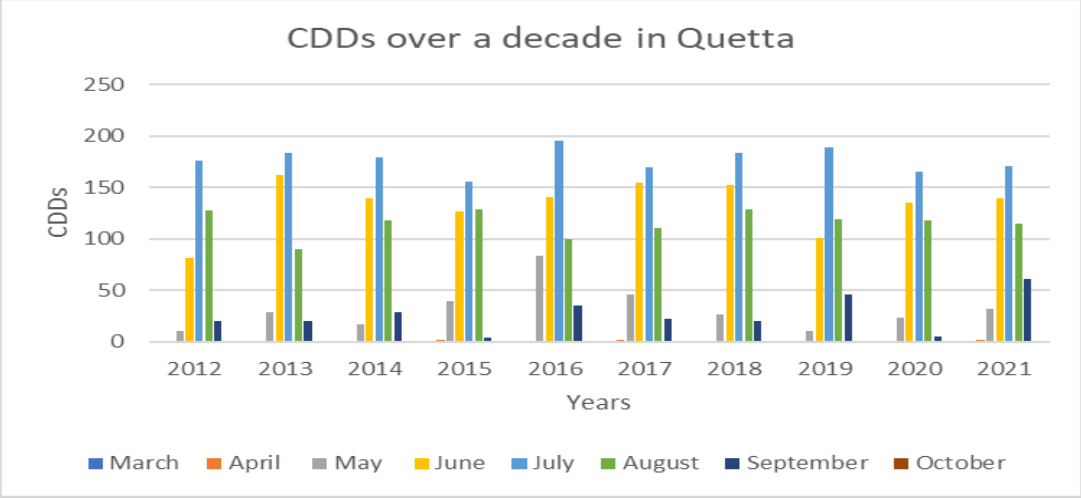



**Fig. 10- CDDs over a decade in Quetta by ASHRAE method**

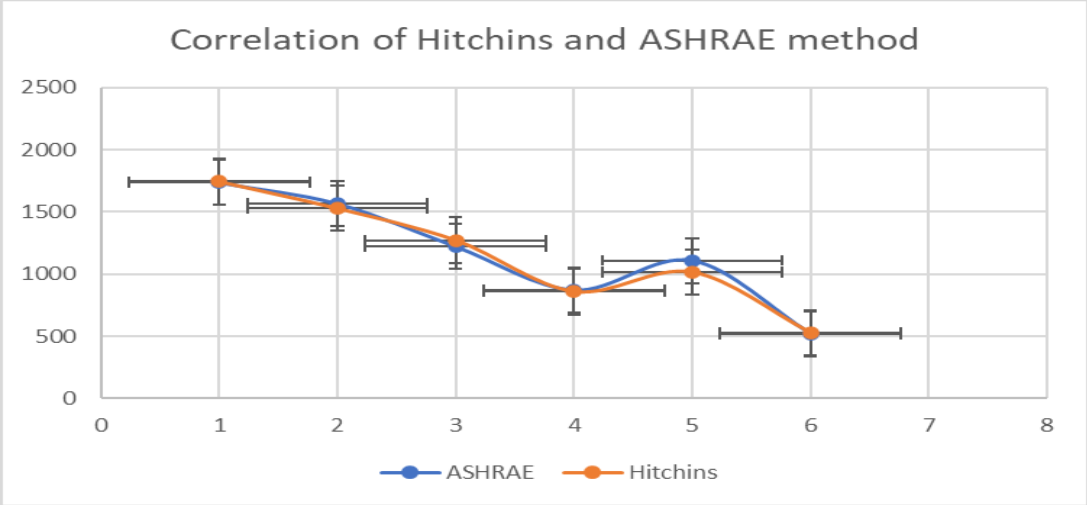



**Fig. 11- Correlation of Hitchins and ASHRAE method.**
**1=Hyderabad, 2=Karachi, 3=Lahore, 4=Islamabad, 5=Peshawar, 6=Quetta.**

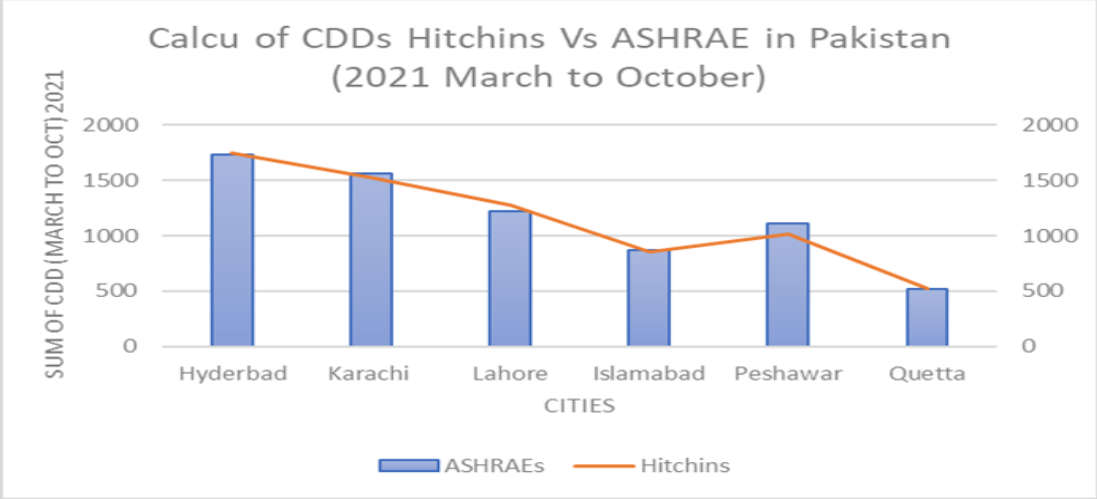



**Fig. 12- Similarity of Hitchins Vs ASHRAE in Pakistan in 2021.**

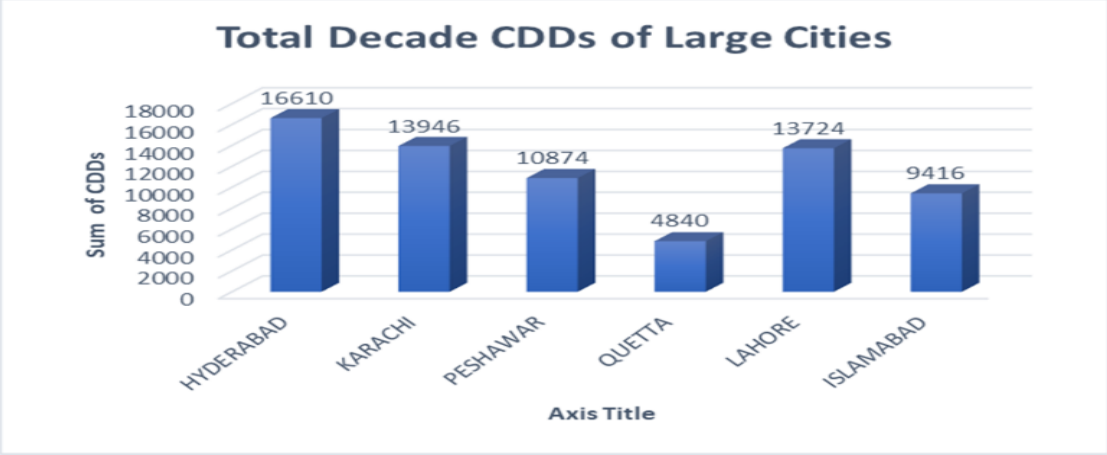



**Fig.13 - Sum of Total decade CDDs of Large cities in Pakistan.**

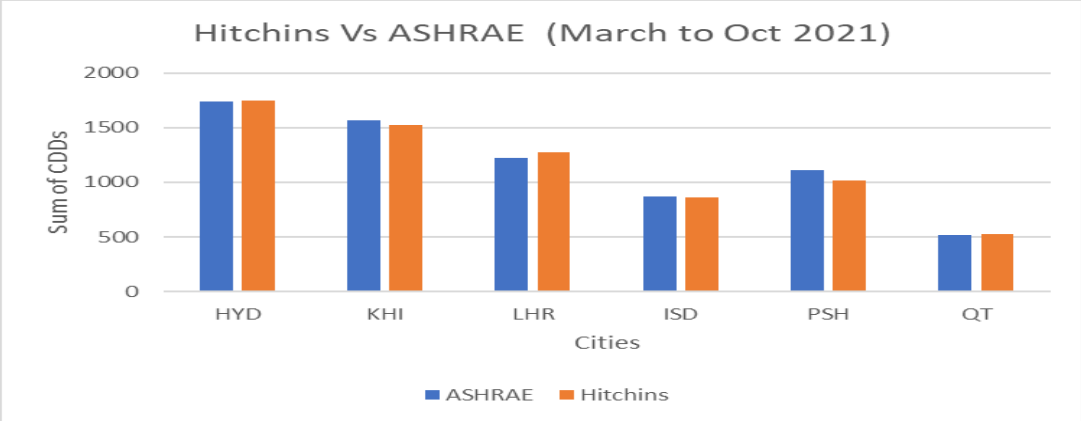



**Fig. 14 - Comparison of Two methods (ASHRAE & Hitchins)**

## 5. Conclusion

In Pakistan most of the years remains warm and the requirement energy is mostly for cooling purpose are in months of March to October, so in this research it has revealed the cluster of different cities and their respective CDDs a simple method to estimate the energy consumption. This energy consumption is mostly accounted for air-conditioning purpose in buildings, and for prediction of monthly degree days for each month of year to that requirement is conveyed to generation companies to manage generation as per the need and distribution companies to manage it from their side. So, in this research it is seen that some cities have high cooling degree days mean they are geographically located on high temperature zones will have high temperature and same trends in respective months of summer if the season is mentioned to predict load for particular season and beneficial for load management as part of energy management system for generation companies. In research it has found that the highest CDDs were for Hyderabad in 2021 as shown in fig 5, 11-14, and whole sum of decade is also highest for Hyderabad and lowest for Quetta in 2021 and in whole decade due to different climatic zones. Hitchens's method and ASHRAE were having same results and it validated the calculation for each of the cities in Pakistan but for Peshawar in some months showed great variations due to the missing data from weather stations for few days and months in Peshawar overall both methods are validated but due to simplicity ASHRAE came out as simple and balanced one due to simple calculation method and mostly authenticated by most of the researchers in world. Monthly averages can be taken from the above data for further analysis. Islamabad and Quetta were having the same results for ASHRAE and Hitchins method of cooling degree days calculation as they belong to same climatic zone. From these, above methods energy consumption per KWH can be predicted for the cities in Pakistan.

## Acknowledgement

I would like to thank my supervisor Dr Rizwan A Memon for his constant support and encouragement throughout my work. I will thank my mother for her untiring efforts to boost my morale to carry out this work, and will also be thankful to all my teachers, family members and well-wishers for their relentless care and support.

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