Climate Change induced warming impacts on energy requirements of Urban built environment: a case of Bhopal

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Abstract— *Climate Change induced warming and Heat Island Effect has become integral part for most of the cities. Global Warming at the present state of technological development is labeled as an irreversible effect. Increased Global warming also triggers and intensifies the Urban Heat Island effect. Particularly for the cities with hot and dry climate, both of these have been addressed as outcome of Climate Change in many parts of the world. Urban centers heavily depend upon electricity for their existence, with increase in temperature electricity demand for space cooling also increases. Climate Change induced temperature rise also affect electrical generation at power plants. Due to excessive cooling demand many cities in India has to overdraw the electrical power from the grid, while the other not so important has to bear the power cuts due to increased demand by others.*

Urban areas are continuously growing larger creating huge demand of electricity for their smooth functioning; Rapid urbanization and improved lifestyle also adds further increase in the electrical demand of the city. Expansions of urban areas are capturing larger areas and, creating a much larger Heat Island Effect on with spreading developments. The already stressed central part of the city has to carry the additional warming due to these developments.

Climate Change has been found to have a direct relationship with the energy demands of cities. Climate Change induced warming and the electricity demand off a city seems to carry a direct relationship. Continuous increase in warming in the future will pose high risk for many cities in the future. This paper is an attempt to establish a relationship between the electricity demands of urban built mass with rise in temperature.

***Keywords—* Climate Change, Global Warming, Cooling Degree Days, Heat Island Effect, Space cooling.**

I. INTRODUCTION

Urban areas are highly active and are major economic center that makes them vulnerable to confront the harsh realities of climate change. Climate change primarily manifest itself by temperature rise, sea level rise and rainfall variability. These manifestations differ for different regions depending upon their location, elevation and climate. The secondary effects of these manifestations are largely flooding, drought, cyclones, storms and fire. These all have heavy impacts on the urban electrical infrastructure if they are not designed to withstand them. Temperature rise has been considered in here as the most important trigger for change in urban electricity demand. Heat island effect is another issue of urbanization being exaggerated by global warming to be considered for immediate mitigation. Growing cities with increased urbanization and heat island effect further intensifies the temperature rise.

India has huge demand and supply shortage of electricity. There is a big gap between demand and supply that is incrementally increasing with vast population growth, urbanization, development and improved lifestyle. This shortage gap is being dealt by power-cuts which are as long as 22 hours in a day at many places. Except for few important cities almost every city faces power cuts. A large part of rural area is not being offered the continued electrical supply.

Urban areas consume the major junk of energy produced and a major part of this is consumed by the Built mass for space cooling and heating. The consumption of electricity is closely associated with the external climatic features like ambient temperature, humidity, wind speed, precipitation and cloud cover. However all these climatic entities are directly affected by climate change and could affect the likely change on electricity demand consumption associated to these changes. The probable daily and seasonal changes in future electricity demand can be can be observed through the future fluctuations in weather patterns. In absence of climate change the scale of change in electricity demand are generally attributed to electricity use pattern and the socio economic development of the locality. The likely improvement in standard of living in India shall increase the use of space cooling and heating, which may change the further sensitivity to climate change. Temperature rise has been accepted world wide to be the most significant factor affecting urban electricity demand. This paper reviews the extent of change in electrical demand due to climate change temperature rise and the probable future impacts.

Relationship between Climate Change and urban energy systems is a growing concern. Cities around the world are making efforts to decrease energy consumption and the linked carbon emissions on priority. On one hand it is being done mainly for locally contained efficiency reasons so as to trim down the effects of high energy costs on household budgets, on the other hand it is done for, to show the growing response to concerns that activities in cities are responsible for a hefty share of worldwide greenhouse gas emissions. Urban energy system adaptations has become an important criteria, because of the growing concern that climate change might have decisive impact on the important supply source or transmission and distribution networks resulting in a massive break down exposing public health and economic strength of a city to severe risk.

For example, in India a big share of electricity is generated by thermal power plants that need lot of water for their operations. To facilitate economical and continuous power generation these power plants were historically placed near water bodies. The majority of these facilities are at risk either by climate change induced flooding or insufficient availability of water due to increased evaporation in summertime. Increases in the summer incidence or length of summertime, heat waves may result in higher rates of sustained electricity demand for space cooling by air conditioning, might result in system breakdown or failure. If continued high demand persists beyond their rated design capacity, it might impose crushing stresses on transmission and distribution networks of the city.

In India, use of air conditioner for space cooling during summertime is in growing fashion because it provides more comforting conditions and requires no water, whereas evaporative coolers require large quantities of water that happens to be in short supply during summertime. Increasing incomes are also facilitating the households to opt for air conditioners irrespective of its huge power needs. Cities that rely on hydropower may be in trouble, if availability of water is reduced during summertime periods, due to changing precipitation patterns resulting from climate change.

The climate change induced warming may not have a disastrous impact on urban power systems, but due to constant overload and bottle necks on generation side it might decrease the resilience of total system in the long run. Replacing the existing infrastructure or upgrading it is not an easy task as it requires large financial inclusions to do it.

Government incur huge amount in repair, maintenance and operation of urban power systems, and most of the time it is highly subsidized also. Looking to the critical importance of power system in cities and its vulnerability towards climate change there is a serious need for a methodology to carry out the relationship between temperature and electricity demand, which may be applied to different urban areas. Although it would be fine and desirable for every study to come to results with the highest level of precision, this is often not possible due to budget or time restrictions. If only a small budget and/or little time are available for a study, quick, easy and approximate methods have to be chosen in order to finish the study under these restrictions.

II. HEADINGS IMPACTS OF CLIMATE CHANGE

In addition to above, as a result of temperature rise the demand for space cooling is increasing and mostly that is being adjusted by higher consumption of water and electricity. Increased demand of water requires more energy for pumping water. Climate change Extremes add to the water crisis and is a threat to the energy security that has large impact on cities. Frequent power failure and low and unsteady voltage affects the performance of equipments resulting in higher electrical consumption.

Extreme heat-wave events are likely to increase in frequency, generating an increase in the peak demand for electricity for air conditioning. The anticipated decrease in annual rainfall may reduce the power supply capacity of hydroelectric dams and the water supply necessary for cooling of atomic / coal-fired power stations for power generation.

Extreme rainfall events could flood power substations. Increased ground movement and changes in groundwater are likely to accelerate degradation of power generation plants, as well as of transmission lines. Flash floods may bring with them a lot of debris into hydro power plants causing disruption of power and decrease in the storage capacity of the dam.

Coastal and offshore gas, oil and electricity infrastructure is at risk of significant damage and increased shut-down periods from increases in storm surge, wind, flooding and wave-events. Sea level rise would worsen these impacts. Increased frequency and intensity of extreme storm events may damage electricity transmission infrastructure and service. More storm activity would increase the cost of power and infrastructure maintenance and lead to more, and longer, blackouts and disruption of services. Increased wind and lightning could also damage transmission lines and structures.

III. STUDY METHODOLOGY

For any given city, local analysis are essential to conclude the overall impact of climate change on energy demand, as it may increase or decrease depending on which of the seasonal effects of climate change (i.e., decrease in energy demand in cooler seasons and increased demand in warmer seasons) are most significant. The climate change vulnerability and impacts for a city and its built environment are location specific, and also depends on the mix of land uses and proportions of building types; therefore a case study approach has been adopted in this study. The city of Bhopal in Madhya Pradesh has been taken as the case study city. The hourly temperature data along with matching energy demands for a suitable period has been analyzed to assess the changes in energy use pattern with respect to temperature changes throughout the year.

IV. THE AREA UNDER INVESTIGATION

To understand the climate change induced warming impacts on the electrical consumption of urban built environment a case study of Bhopal has been carried out. Bhopal is the second largest city of the state of Madhya Pradesh. It is situated at 77°25’ E longitudes and 23°15’ N latitude. It is also the capital city of state of Madhya Pradesh. The city falls under the Tehsil Huzur of Bhopal district. Rapid urban growth and industrialization have brought tremendous changes in the city. Bhopal has grown from a Mogul fortress and city-state to a thriving educational and industrial hub, with many top research institutes, over one hundred engineering colleges, a dozen international schools, more than a dozen of management colleges and more than hundred science, arts and commerce colleges.

As per the census 2001 & 2011, Bhopal was 17th & 20th largest city in India respectively. On the economic front the city is growing as a multifunctional capital city. The city has lot of migrants hence has cosmopolitan culture with higher education levels. In a recent assessment Bhopal has ranked 77 in the list of fastest growing cities in the world with an annual average projected growth of 2.69%, between 2006 to 2020 (http://www.citymayor.com), though it stands at 18th amongst 25 Indian cities which figure in the list. Urban population of Bhopal has increased at an average decadal growth rate of over 70% during the last 4 decades. Bhopal with a population of 85,000 in 1956 at the time of declaring it is as a State Capital was confined within the walled city has grown into a metropolis with 10.63 lakhs in 1991, 14 lakhs in 2001 and 18.8 lakh in 2011 as per the census 1991, 2001 and 2011. The longer perspective and various estimates indicate that the city would grow to around 35 lakhs by 2021.

V. AIMS AND OBJECTIVE:

The basic aim of the study is to carry-out a methodology for assessment of Climate change induced warming impacts on urban built environment. The objective of this study is to give only a quick and approximate overview of the impact, therefore a less precise, less costly and less time-consuming method might be sufficient and appropriate.

VI. CONCEPTUAL TOOL & RESEARCH METHODS:

The urban electricity demand has close relation with temperature rise is the key hypothesis of this study. Majority of the urban electricity demand comes from the built environment therefore it is essential to study the electrical consumption pattern of built environment. Since the vulnerability and impacts of climate change for built environment are location specific therefore a case study approach has been adopted in this study. The city of Bhopal in Madhya Pradesh has been taken as the case study city. The hourly temperature data along with matching energy demands for a suitable period has been analyzed to assess the changes in energy use pattern with respect to temperature changes and to estimate the likely energy needs in different temperature conditions.

In this study we have explored the parameters which describe the linkage of change in temperature with electricity consumption using regression analysis. For this purpose change in temperature was analyzed with electricity consumption for the year 2007-08. This linkage has been studied through an analysis of hourly temperature data with hourly electricity consumption. One of the objectives is to establish a system of data analysis that can be used for further assessment studies of similar nature. This is possible through proper recording of data in a suitable format/ system so that it can be used further and save the time.

Primarily the study needed hourly temperature and electricity consumption data. This was available from two different sources. The temperature data was obtained from the 'Online Climate Data Directory' available at the web site of National Climatic Data Center of the US Department of Commerce. [http://www.ncdc.noaa.gov/oa/ncdc.html]. The data available from the website is at three hours interval and the hourly readings were obtained by linear interpolation of the data.

The electricity data was made available by the Madhya Pradesh Madhya Kshetra Vidyut Vitaran Company Limited (MPMKVVCL). The MPMKVVCL has electronic monitoring of the power consumption at different feeder lines. The data is recorded at 30 minutes interval for all major feeder lines above 11 KV in Bhopal city. The data made available was for duration of one year from July 2007 to June 2008. Out of 17 MRI readings only one feeder (Habibganj-II) was short listed on merits. The 30 minutes interval readings for this feeder were modified to hourly frequency for better comparison with temperature data.

The data has been cleaned up for removing the effects of power cuts, outages, spikes and by removing important holidays and festivals that occurred during the year 2007-08. This cleaned up data has been used to explore the relationship between temperature and electricity consumption. In the primary observation it was found that the relation between the two datasets has strong seasonality effect, therefore the analysis was done for three different seasons of four months each, i.e. Warm humid season (July-August-September-October); Cool dry Season (November-December-January-February); and Warm dry season (March-April-May-June). The results of the analysis are presented below.

Warm Dry Season (March-April-May-June)

During warm dry season, at night between 21 to 5 hours the electricity consumption is gradually increasing with rise in overall temperature. The electricity chart is well correlated with temperature chart as there is very less activity; the two charts run parallel and show similar patterns.

During 13 to 17 hours the electricity usage increases over the months and fluctuates less in comparison to temperature. This may be due to the fact that afternoons are generally warmer than forenoon and there is constant need for space cooling and ventilation. On the other hand the heat-gain in the buildings due to external reasons is more which increases the electricity demand for space cooling. Broadly the electricity usage and temperature curves follow the same locus but due to constant demand and load some fluctuations are observed in electricity usage. There are sharp declines observed in electricity consumption during late afternoons on some days which may be due to outages (Figure 1).

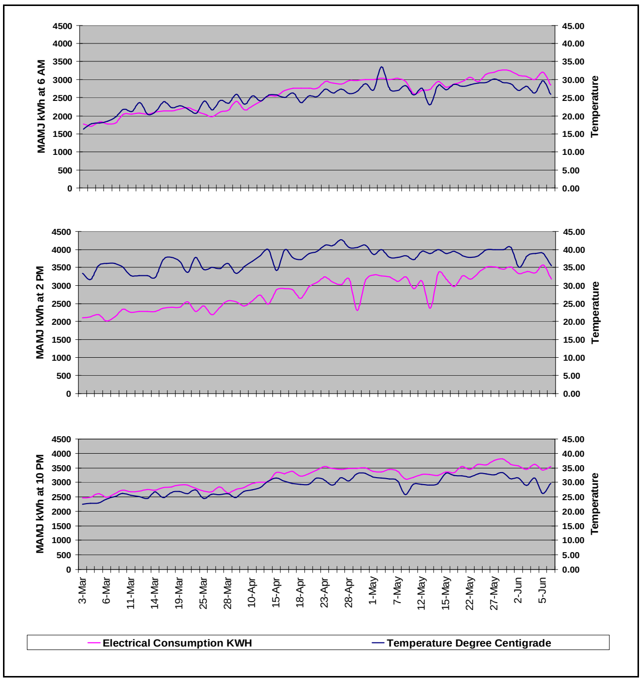

Figure 1: Temperature and Electricity Consumption for Warm Dry Season

Warm Humid Season (July-August-September-October)

In warm humid season, during the night from 21 hours to 5 hours the electricity consumption data is well correlated with temperature as there is very less activity; the two charts run parallel and show similar patterns; it shows that the electricity consumption is very much sensitive to temperature data as there is no or very little human activities during night.

During early morning 6 to 8 hours the two charts show similar patterns but sensitivity of electricity consumption to temperature decreases due to increase in activities. The change in electricity consumption follows the pattern of temperature but the peaks and dips in electricity chart are much more stabilized.

During the day i.e. between 9 to 17 hours the electricity demand is stable and fluctuates within a small range even with wide variations in temperature. It may be because of the fact that the higher demand from activities such as lighting and other appliances may be masking the effect of temperature in the total demand. There are sometimes unexplained decline in the electricity consumption during the day which may be due to short duration outages and electricity supply failures (Figure).

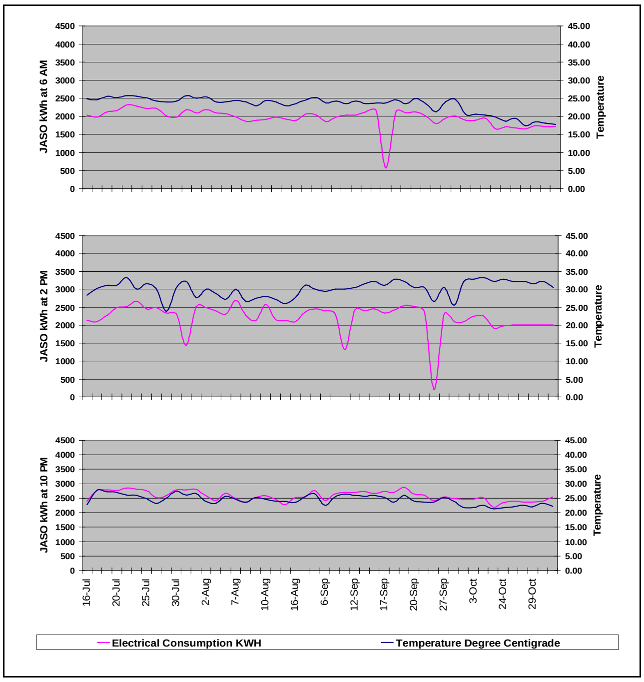

Figure 2: Temperature and Electricity Consumption for Warm Humid Season

Cool Dry Season (November-December-January-February)

In cool dry season, during the night between 21 to 5 hours the electricity consumption is more or less constant and range bound as there is very less activity and there is no space cooling demand. During the month of November and again in February there are mixed patterns. This is possibly because the night temperature begins to fall from the month of November and whenever the temperature falls below the comfort level the need for heating is generated and the two charts tends to drift slightly in opposite directions.

During 6 to 8 hours in the month of November the two charts show similar patterns but sensitivity of electricity chart to temperature chart decreases as we proceed towards the end of the month this is due to overall temperature decrease and increase in daily activities; December to February the two charts show opposite patterns, i.e. with fall in temperature the electricity consumption increases and vice versa. This indicates a possibility of heating demand due to presence of lower temperatures (below comfort limits) during these months.

During 13 to 17 hours the electricity consumption becomes more stabilized and fluctuates very little within a range despite substantial changes in temperature. This may be due to the fact that afternoons are generally warmer than forenoon and there is heat-gain in the buildings due to external as well as internal reasons which decreases the electricity demand for space heating (Figure 3).

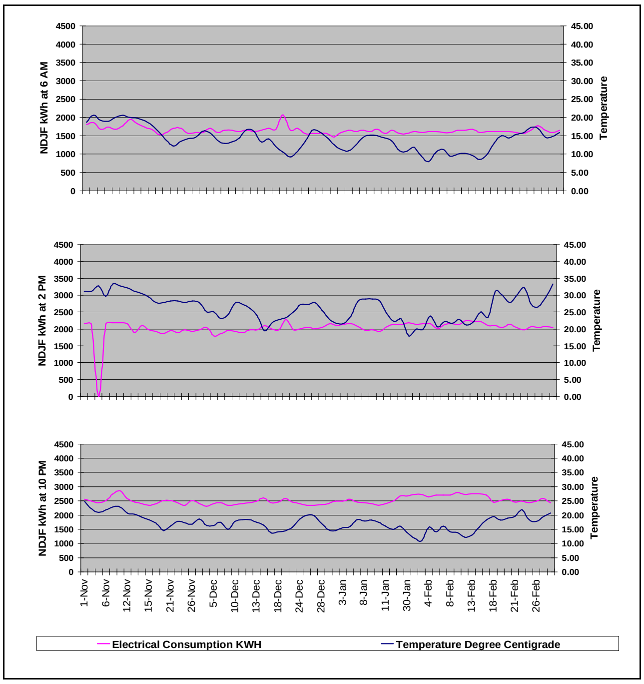

Figure 3: Temperature and Electricity Consumption for Cool Dry Season

Overall, during this period the electricity consumption is lowest in the year as the need for cooling is almost absent and winters in Bhopal are not severe hence require very little or occasional space heating; most of the buildings do not have any space heating appliances installed as building enclosure is sufficient to provide the protection against winters.

VII. CONCLUSION

From the data analysis presented in the previous section it is clear that the electricity demand, in absence of a high demand for other activities and electrical appliances, depends on the temperature change. Moreover, it increases with increase in temperature during summer months and increases with decrease in temperature during winter months. Thus, for establishing the relationship between temperature change and electricity consumption, definition of comfort limits and calculation of heating and cooling hours during the day may prove to be useful. With the availability of hourly temperature data it is possible to calculate the number of hours when cooling or heating would be required. The Cooling Degree Hour (CDH) is sum of cooling requirement and Heating Degree

Hour (HDH) is sum of heating requirement when the temperature is outside the comfort limits in any hour. The CDH and HDH for comfort limits ranging from 15 to 30 degrees centigrade were calculated. However, it was observed that very little or negligible HDH were found in comparison to CDH, which shows that there is very little requirement for heating in the city, therefore HDH was not considered for this study. A regression analysis of daily total KWh with daily total CDH at various comfort limits of temperature were done to ascertain the best fit CDH temperature. It was observed that best fit value calculates at 25 degree centigrade. Based on this, the CDH calculating temperature was finalized at 25 degree centigrade.

A final regression was done between daily total CDH values for 25 degree centigrade and daily total kWh consumption to work out the best linear relationship between the two. Based on the regression results, the linear equation reads as (Y=139.61X + 48790.46) Where X is the value of daily total CDH and Y is the daily total KWh. Thus, the regression outcome shows that the average daily consumption of the selected feeder in the study area within comfort temperature range (i.e. CDH=0) is 48790.46 kWh, whereas for every degree rise in temperature above comfort temperature for one hour duration additional 139.61 kWh of electricity is consumed.

Identification of problem and vulnerabilities is not a single step process. Policy and decision makers need to understand the extent of problem and its impact over the infrastructure in specific and society in large. Attempts should be made to identify the mitigation measures that can be implied in phases with regular development such that providing reduction of problem as well as adding value to the society. Cities can take tough steps to decrease their energy demand and thus their carbon emissions, and it is increasingly clear that many of these steps also provide significant adaptation benefits.

Cities can play a vital role in environment management. On one hand well managed environmentally sustainable cities contributes to the health, welfare and productive capacity of their own citizens; on the other hand they can also make a major contribution to the world environment. There is a strong correlation between urbanization and economic development, Urban areas relying on urban infrastructure are the largest and most efficient generators of new job, with easy access to markets and supplies.

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