Effect of climate change on energy demand: Case study of IIT-Bombay

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- Objectives
- Literature review
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- Methodology
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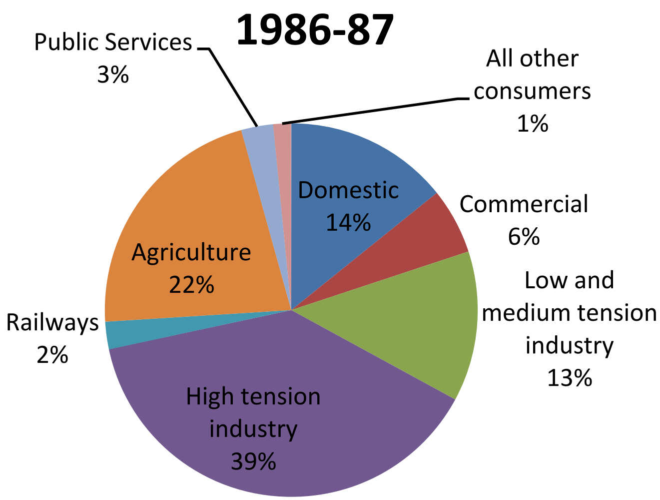
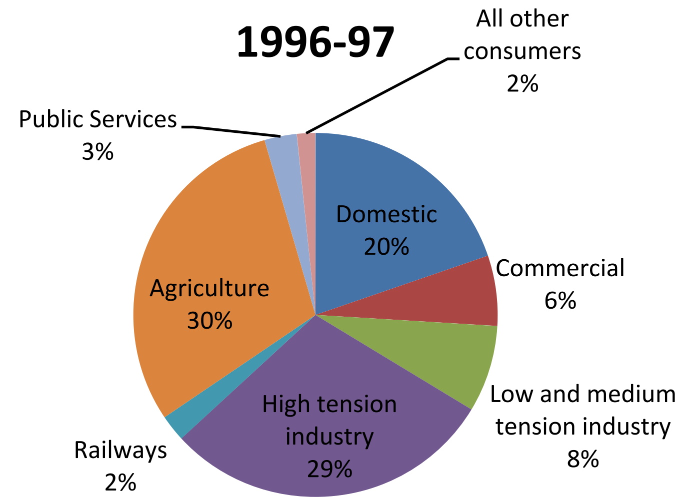
Motivation for the study

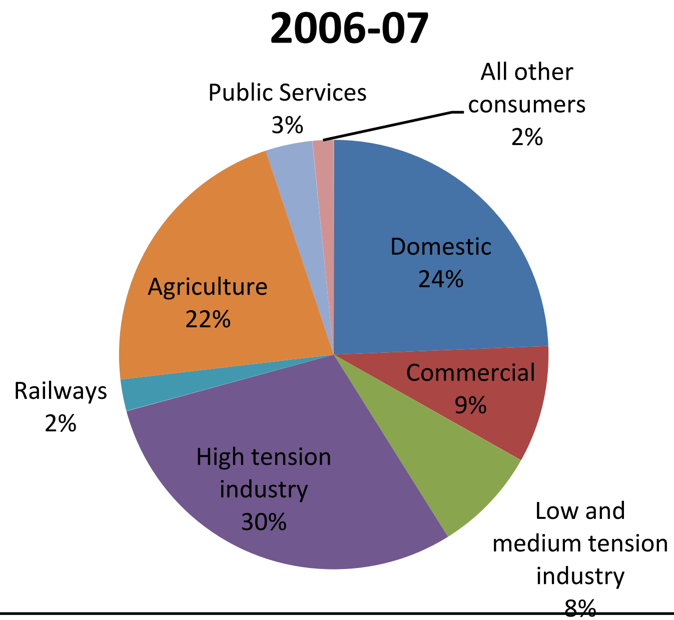
The IPCC fourth assessment report says that:

- The direct energy-related CO_2 emissions of the building sector including electricity use are about 8.6 Gt/yr, almost a quarter of the global total carbon dioxide emissions
- The largest regional increases in CO_2 emissions (including through the use of electricity) for commercial buildings were from Asia (30%)
- Non-CO_2 emissions (largely halocarbons, CFCs, and HCFCs, covered under the Montreal Protocol and HFCs) from cooling and refrigeration contribute to more than 15% of the 8.6 Gt CO_2 emissions associated with buildings.
- 60% of these halocarbons were from refrigerants

Consumption pattern of India







Research needs

- Most of the research in this area is only in the US, OECD countries and Australia*(Source: Parkpoom et al.)*

- Domestic electricity consumption of India in 2006-07 was double that of 1986-87 *(calculated from CMIE data)*

- Increasing electricity demand has impacts on:
  - Finances of electricity supply
  - Power shortages
  - Increased CO_2 emissions due increasing use of fossil fuels

- This highlights the need to undertake research on the effect of climate change on energy demand

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Objectives

- To study consumption trends for different residential / commercial areas
- To study temperature trends
- To identify different explanatory variables (apart from climate variables) on which the consumption would depend
- To build models and compare
- To forecast energy consumption under different scenarios

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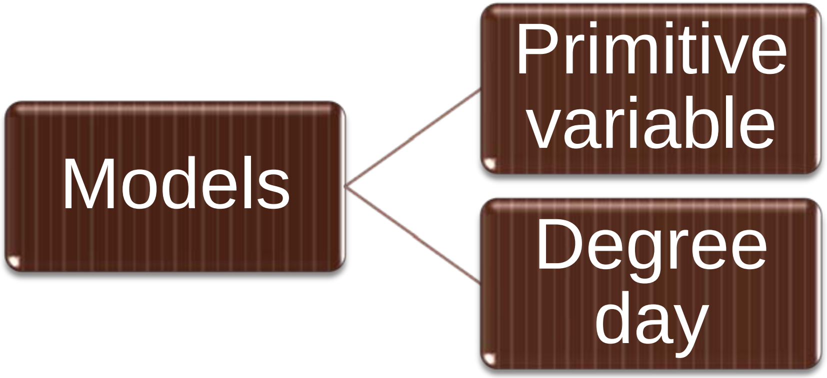
Summary of recent studies

Reference	Location	Model	Projected period	Scenarios considered	Projected demand change (%)
Hekkenberg et al. (2009)	Netherlands	Primitive	NA	NA	NA
Lam et al. (2009)	Hong Kong	Degree day	2009-2100	B1, A1B of IPCC	12.5%
Isaac et al. (2008)	Global	Degree day	2000-2100	Different IPCC scenarios	34% increase in heating demand, 72% increase in cooling demand
Zmeureanu et al. (2007)	Montreal, Canada	Degree Day	2040-2069	A2x (average of A21,A22, A23 of IPCC)	Reduction in heating demand by 7.9 t0 16.9%
Sailor et al. (2001)	LA, USA	Degree day	NA	CDD increase of 20%	1–9%

Modeling of electricity demand in the context of climate change

- Most models in literature are econometric.
- The models used are classified on the basis of the nature of the independent variables used for regression:
- ***Primitive variable models***, in which the climate variables are used as they are
- ***Degree day models***, in which temperature data are converted to degree days.



Introduction to Degree days

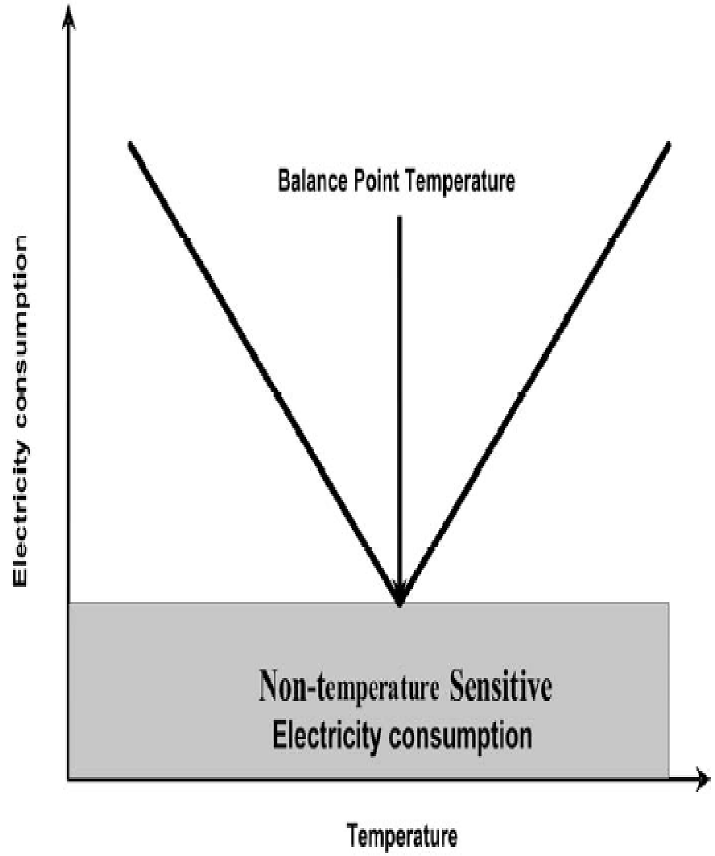
- Degree days are constructed from available climate data.
- Usually used by energy managers to '*normalize*' historical consumption data with respect to climate.
- Degree-days are essentially the summation of temperature differences over time, and hence they capture both extremity and duration of outdoor temperatures.

Introduction to Degree days

- The temperature difference is between a reference temperature and the outdoor air temperature.
- The reference temperature is known as the *base temperature*
- The base temperature is the outdoor temperature at which the cooling (or heating) systems do not need to run in order to maintain comfort conditions.

Concepts of Degree days

- When the outdoor temperature is above the base temperature the cooling energy requirement from the air conditioning system increases.
- Similarly when the temperature falls below the base temperature, heating is required.
- The amount of cooling or heating required, at any point of time depends on the difference of indoor and outdoor temperatures .
- Therefore, the energy consumption of a cooled or heated building over a period of time should be related to the sum of these temperature differences over that period.

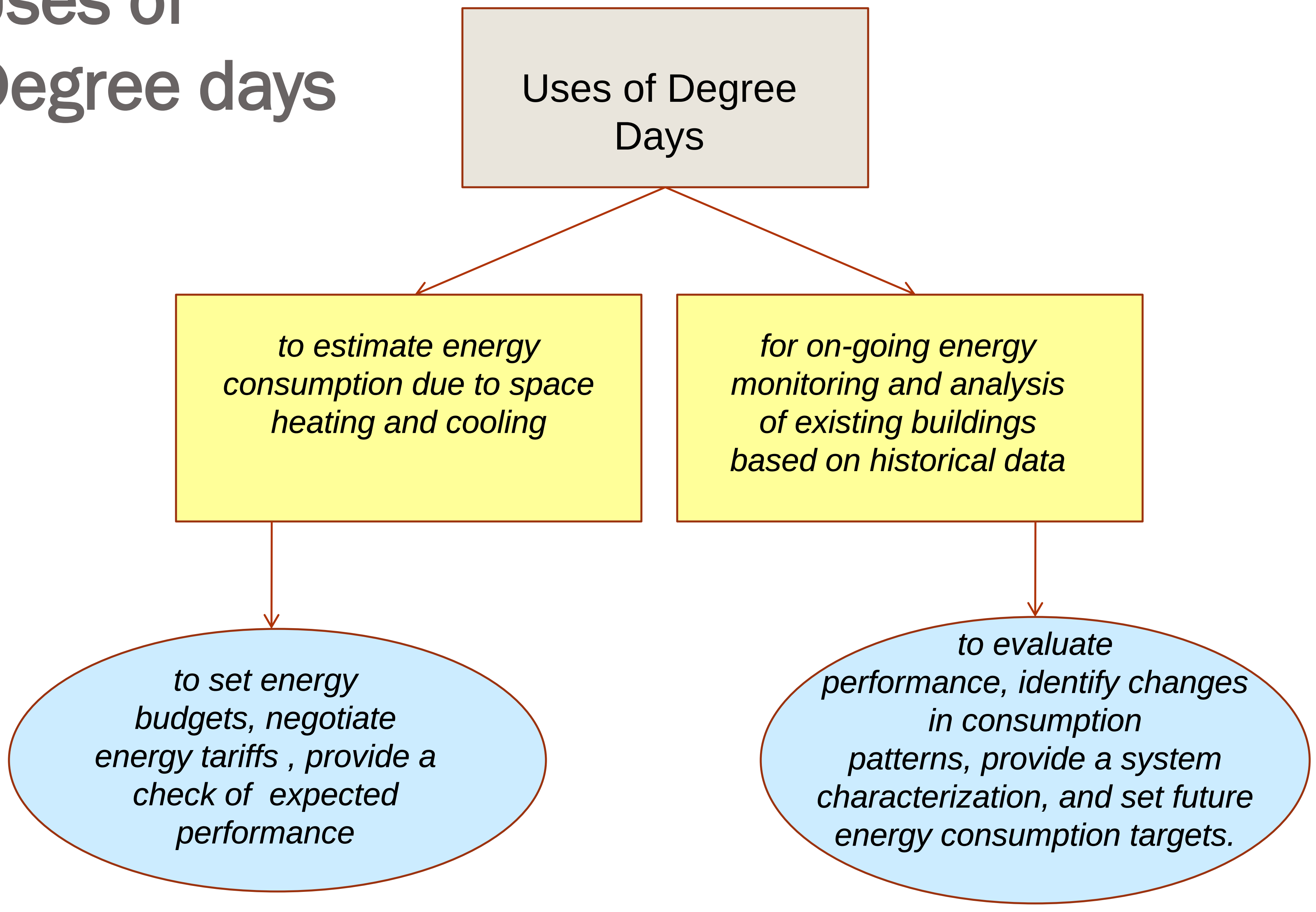


(Source: Parkpoom et.al.)

Degree days Concepts

- Degree days are of two types: Cooling degree days (CDD) and Heating degree days (HDD) .
- CDDs are used to analyze the cooling energy requirements of buildings. CDDs are indicative of how many days in a month (in the case of monthly CDDs) and to what extent cooling was required to bring the inside temperature to a comfortable level.
- HDDs are used to analyze the heating energy requirements of buildings. HDDs indicate how many days in a month (in the case of monthly HDDs) and to what extent heating was required to bring the inside temperature to a comfortable level.
- Both HDDs and CDDs are calculated with respect to a base temperature T_b

Uses of Degree days



Methods to calculate degree days

- With daily mean temperature data, CDDs and HDDs are evaluated as follows: *(Source: CIBSE)*

  (These equations are an approximation of the Integrals:
  $CDD = \int (T - T_b)\, dt$ and $HDD = \int (T_b - T)\, dt$)

$$\mathrm{CDD} = \sum_{d=1}^{N_d} (\gamma_d)(T - T_\mathrm{b}) \qquad \mathrm{HDD} = \sum_{d=1}^{N_d} (1 - \gamma_d)(T_\mathrm{b} - T).$$

where γ_d = 1 when $T > T_b$ else 0;

N_d is the number of days in the month,

T_b is the base temperature

Degree day calculations

- The monthly electricity demand is then modeled as:

$$E = a + b\ (CDD\ or\ HDD)$$

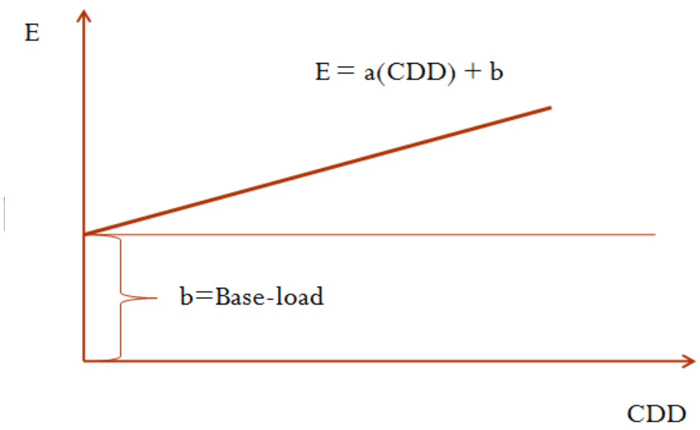
- The cooling demand or heating demand is proportional to b

- “a” signifies climate insensitive component of the demand

Demerits of degree day approach

- *The Base temperature problem*:
  - Might be variable throughout the year.
  - Hugely affects degree day calculation

- *The base-load problem*:
  - With a small change in base temperature, tempe insensitive load might vary drastically!



- *Intermittent cooling*

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IIT-Bombay

- Latitude, Longitude: 19.08^0 N ,72.55^0 W
- Total area: about 500 acres (2023428 sq.m.)
- Total residential floor area: 80,302 sq.m. (4% of total area)
- Total connected load: 5.3 MW (as on April 2008)

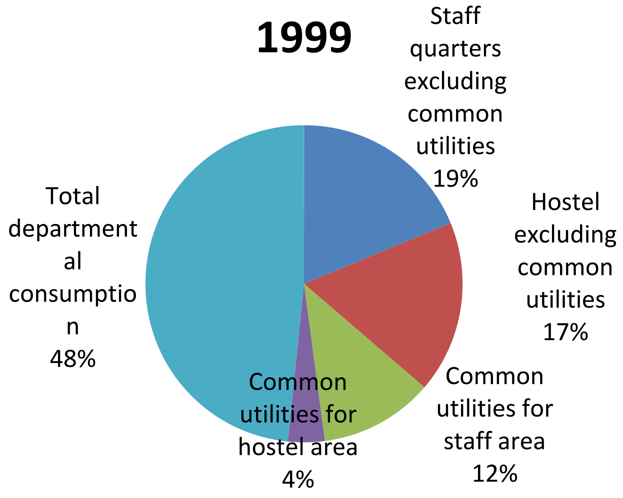
Why IIT-B?

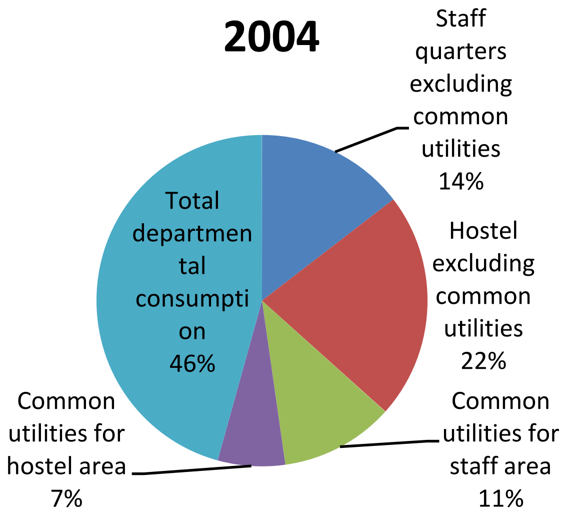
- We want to capture extremities in the relationship between energy demand and climate change.
- In closed areas like IIT-B, there have not been many power cuts and the response we get should be worth analyzing.
- ***We are interested in studying similar campuses to widen the scope of the work and to get a proper geographical cross-section***
- Mostly, availability and accessibility of data is a primary concern

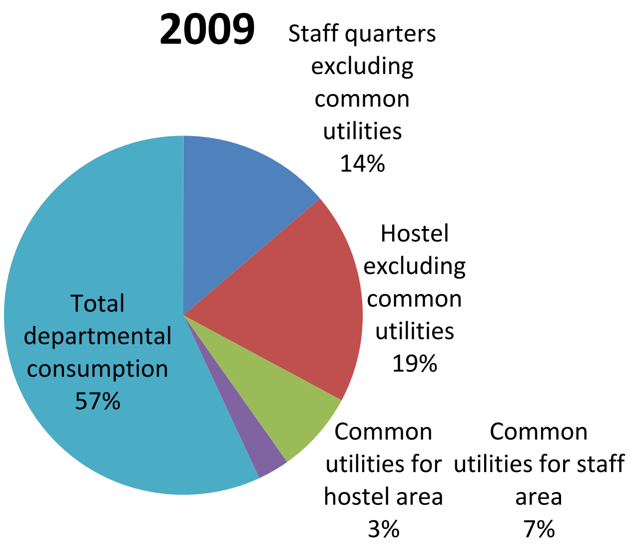
Available data

- Gridded temperature data (min, max and mean) for the period of 1978-2005 *(Source: IMD, Pune)*
- Temperatures for Mumbai were extracted from this
- Historical consumption data for residential area of IIT-B *(Source: electrical maintenance section of IIT-B)*
- Economic indicators: GDP/capita, Personal Disposable income/capita *(Source: Economic Intelligence Services, CMIE)* and wholesale price indices for domestic electricity use*(Source: www.rbi.org)*
- Other data like number of employees is being acquired.

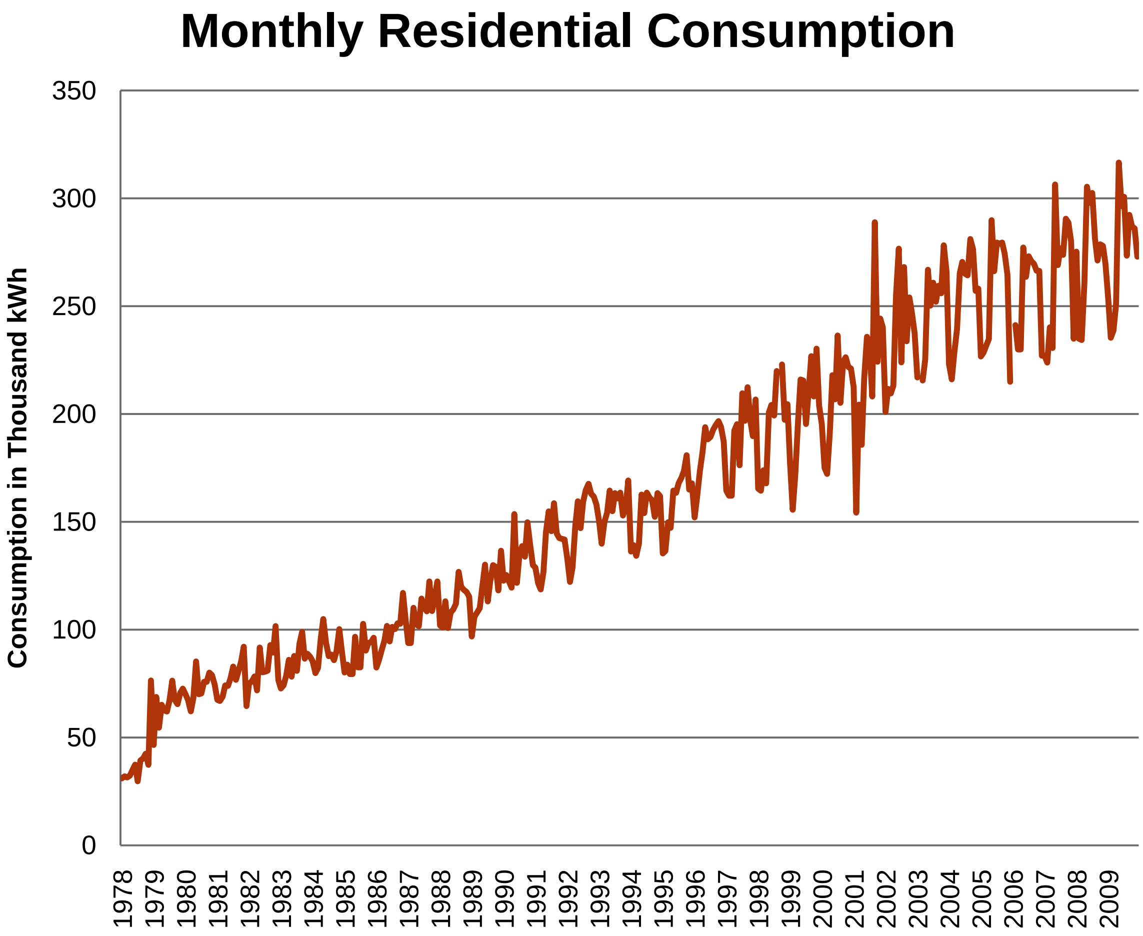
Consumption patterns in IITB







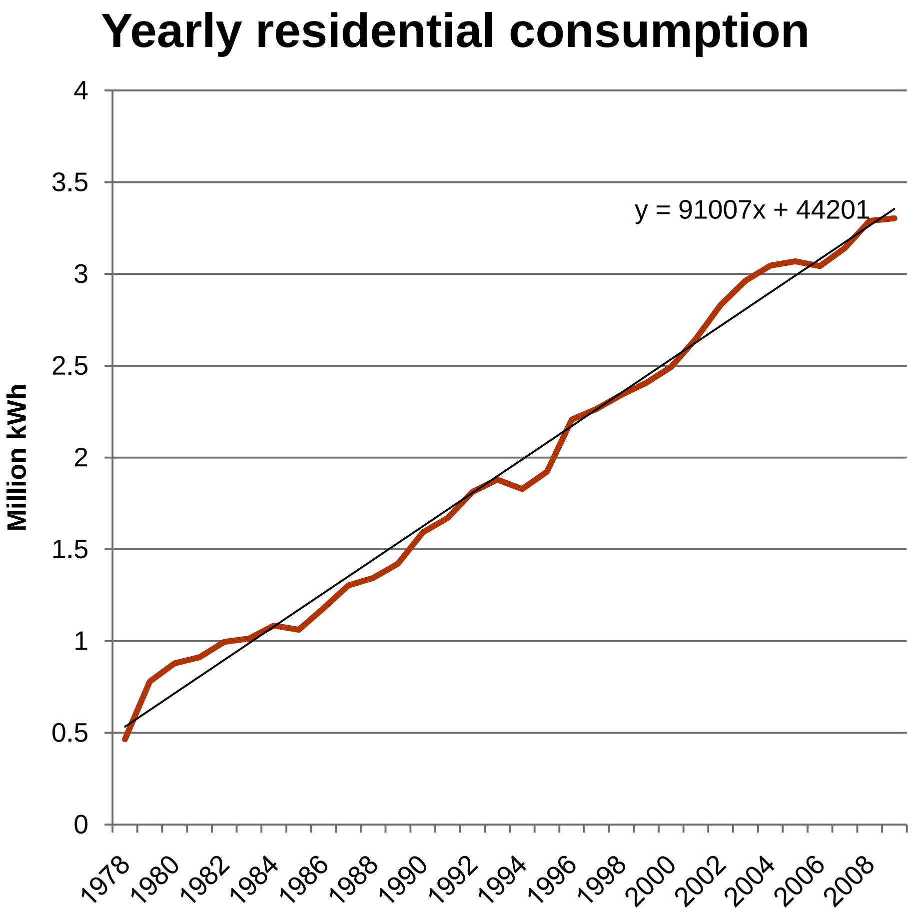
Residential consumption of IIT-B



- The residential consumption of IIT-B has increased from about 40,000 kWh per month in 1978 to about 3,00,000 kWh per month in 2009

- This is an increase of about 650% !

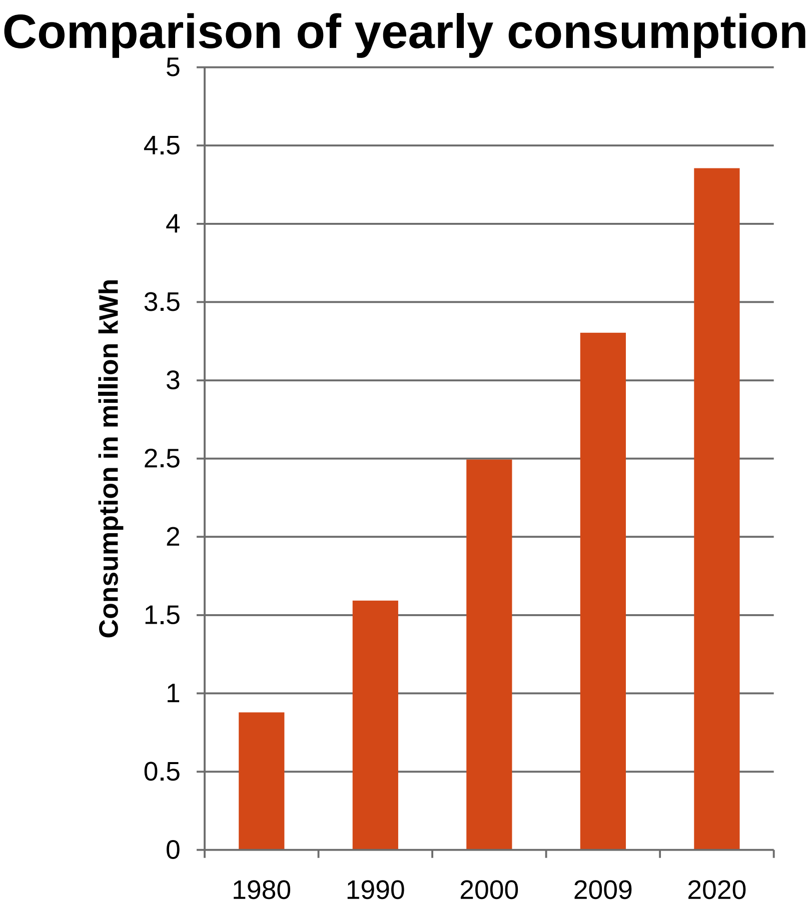
Yearly Consumption trends



- The yearly consumption is changing, on an average at a rate of 91,000 kWh per year.
- If this trend continues, then consumption in 2020 would be around 43.5 lakh i.e. 31.6 % higher than 2009.

Some numbers....

- The residential consumption of IIT-B is increasing by almost 8 lakh kWh per decade.



Consumption per unit area vs Consumption per capita

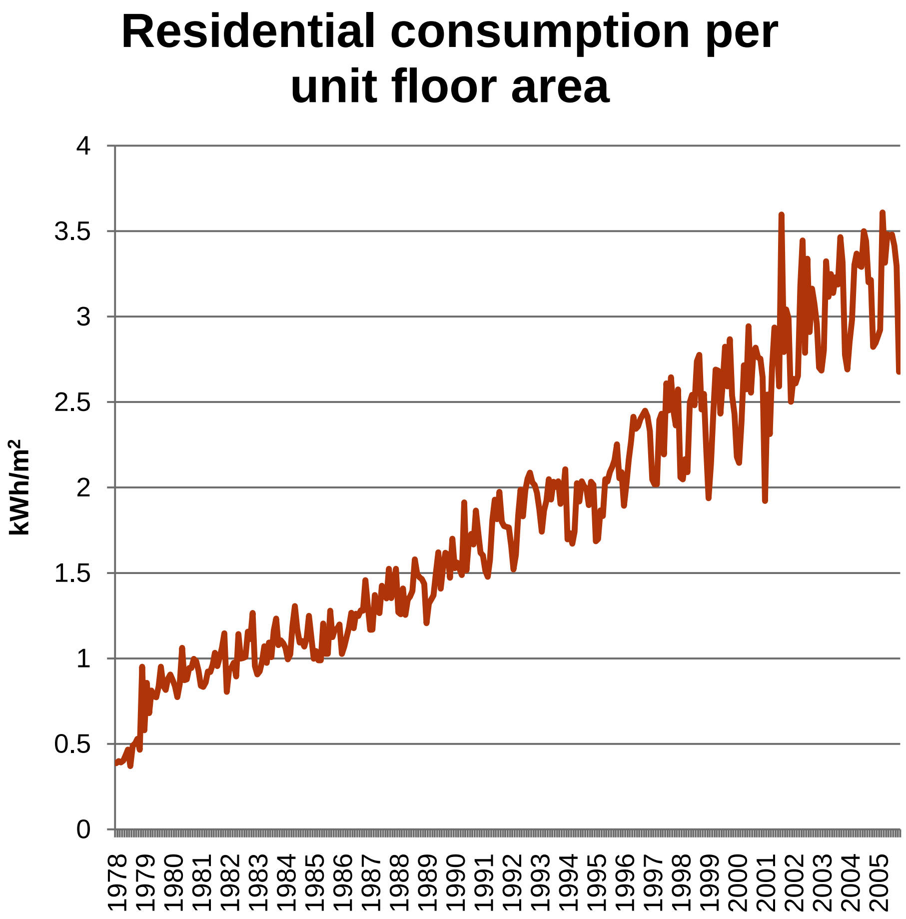
Consumption per unit area

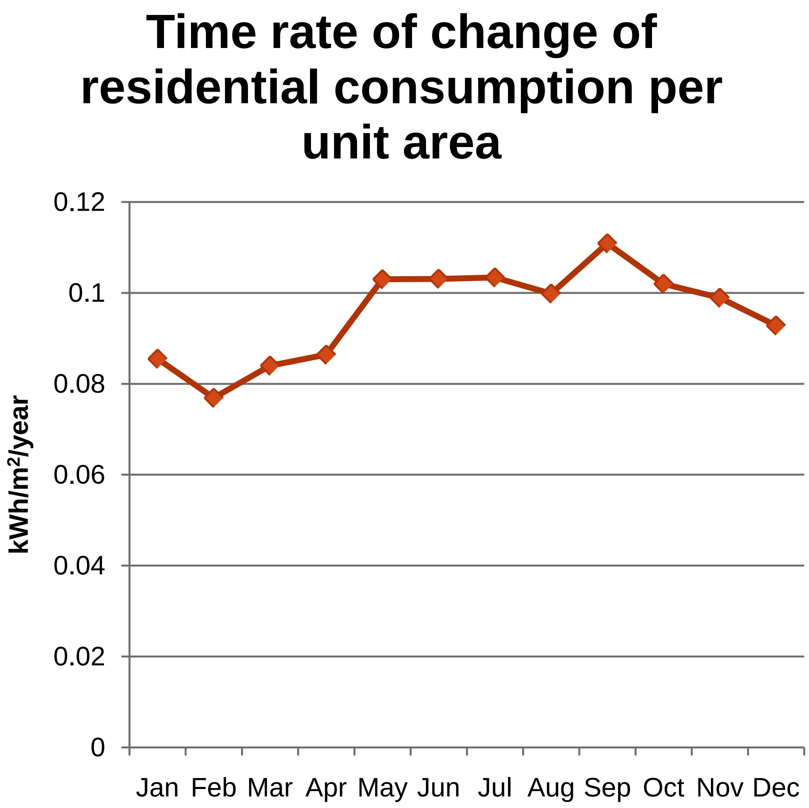
- Area details easily available
- Gives an idea of the energy intensity
- Cooling energy consumed would most probably depend on area than on number of people

Consumption per capita

- Population details difficult to get
- Very stochastic in nature i.e. we would not have idea about guests , etc.

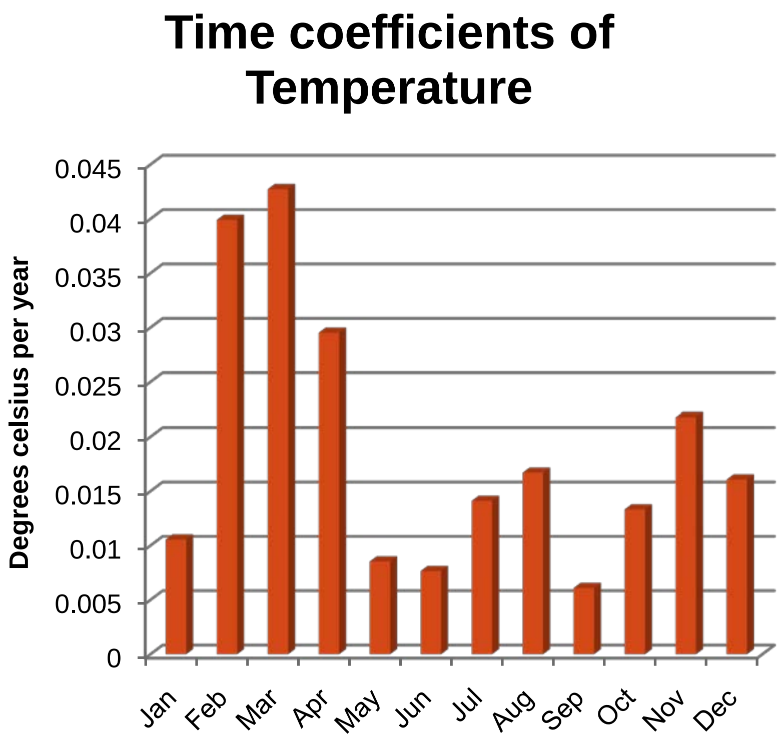
Electricity consumption per unit floor area



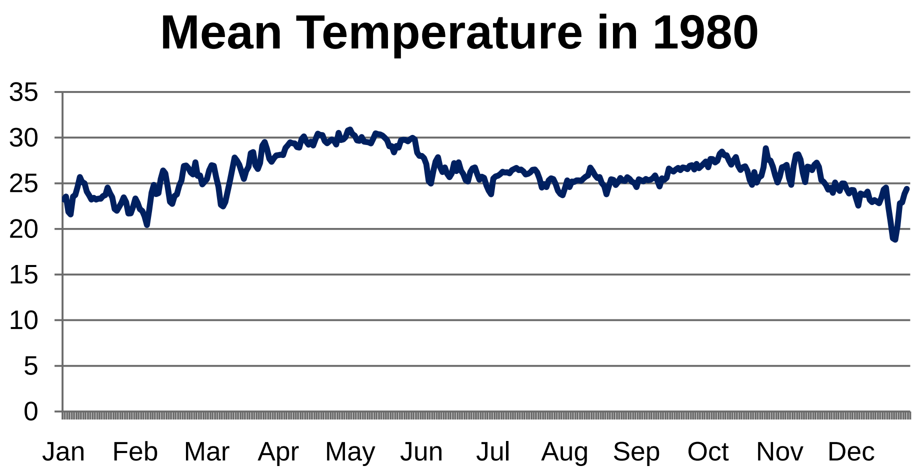


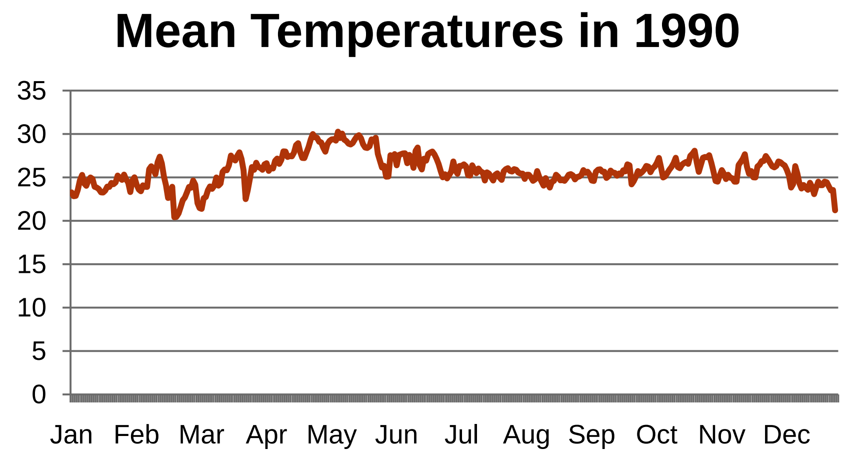
Month-wise Temperature trends

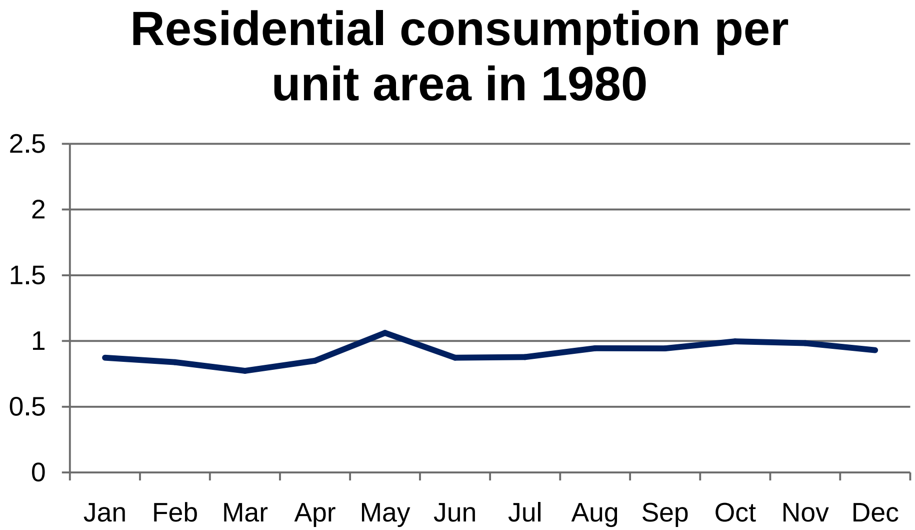
- Temperatures have risen fastest in the months of Feb, Mar and Apr at a rate of 0.039, 0.042, 0.029 C per year respectively.
- Temperature coefficients for Jan, Nov, Dec are significantly higher than May, Jun
- So, winter months are becoming warmer faster than summer months!

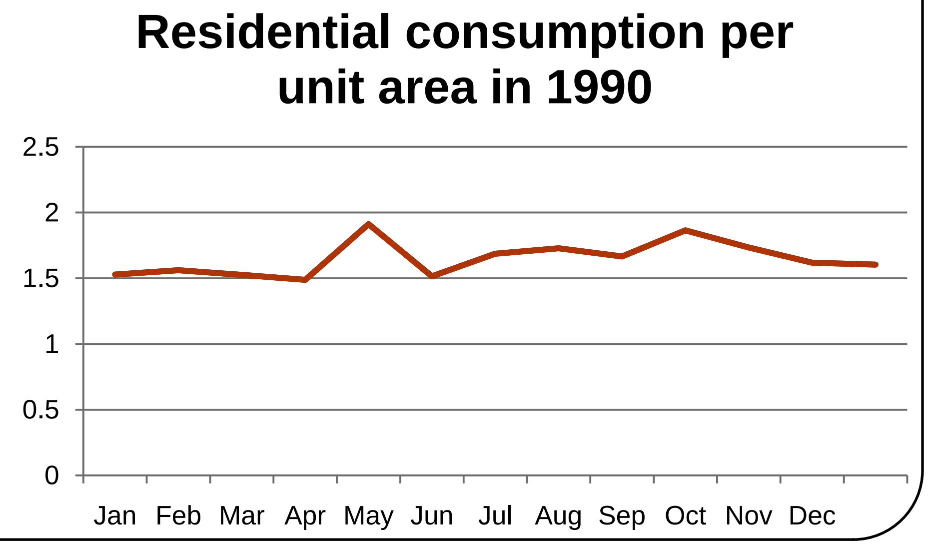


Consumption-temperature trends

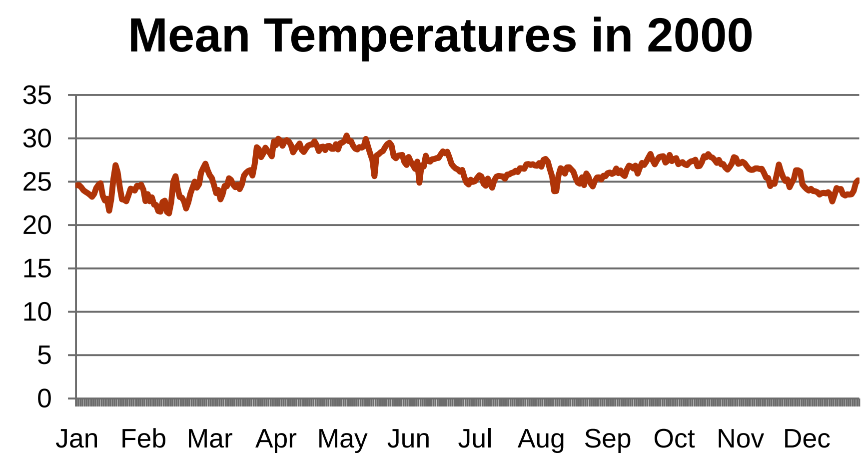


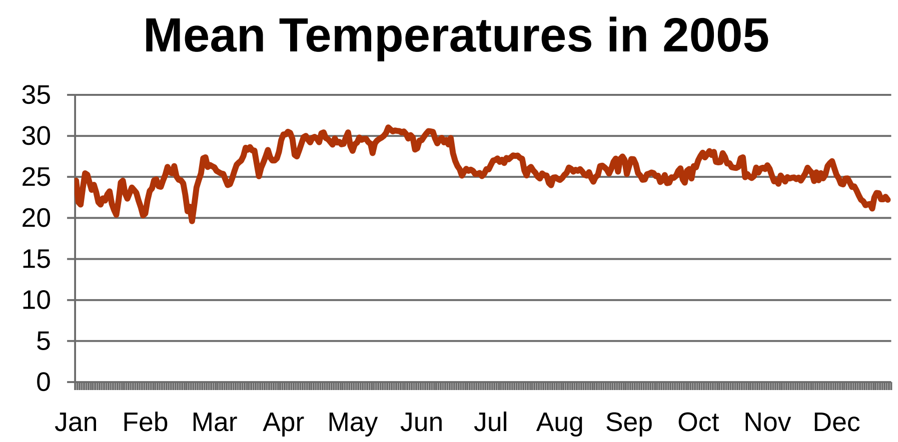


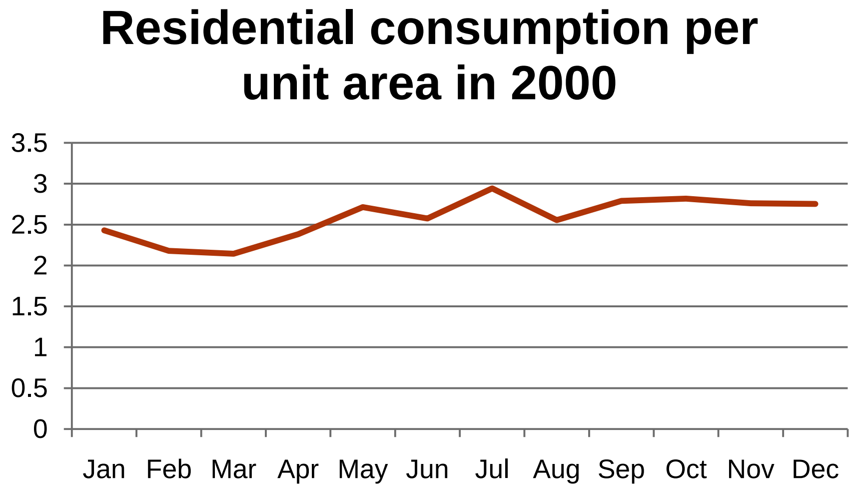


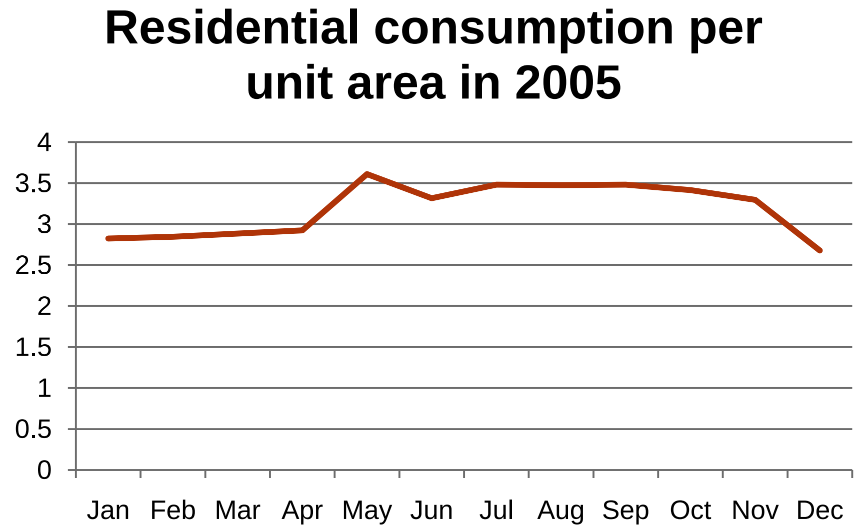


Consumption-temperature trends

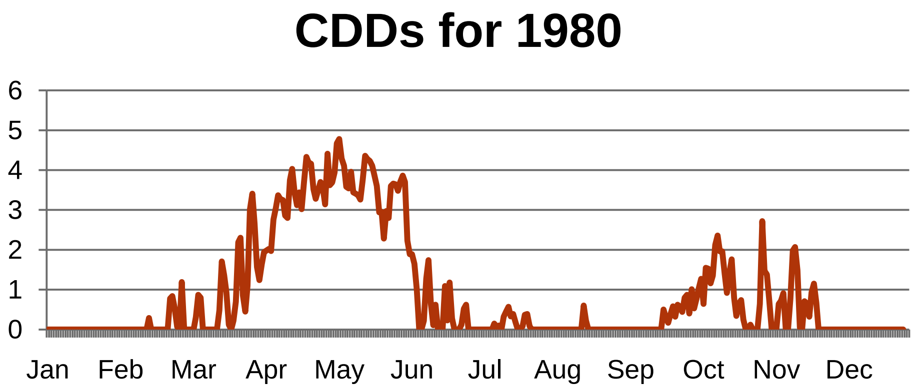


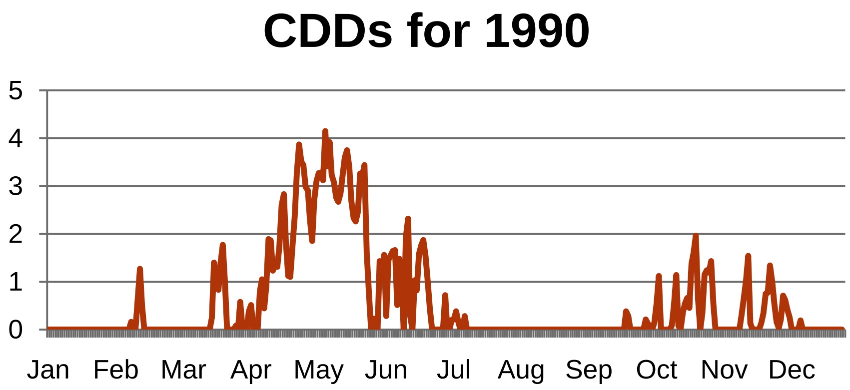


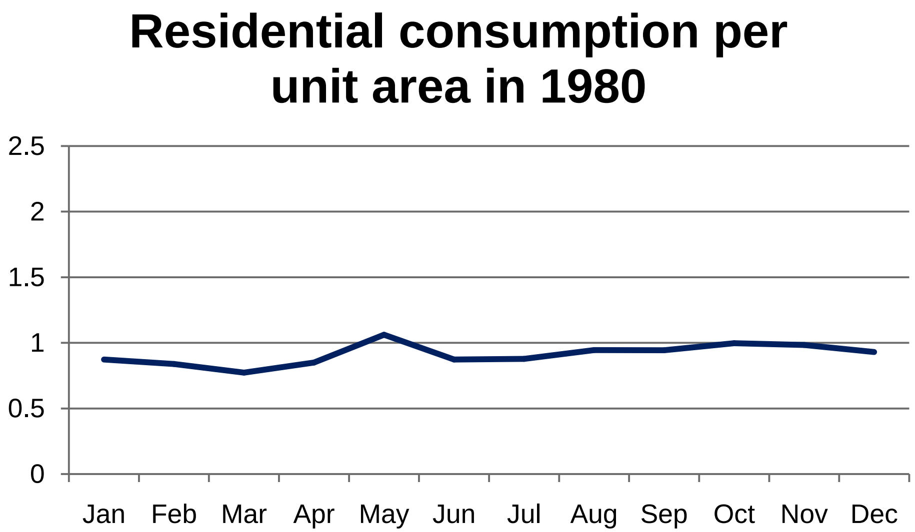


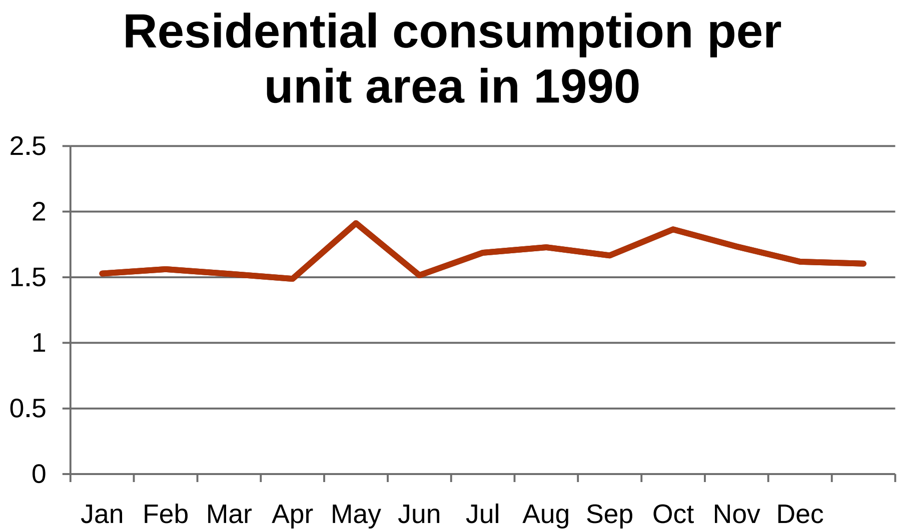


Cooling degree days

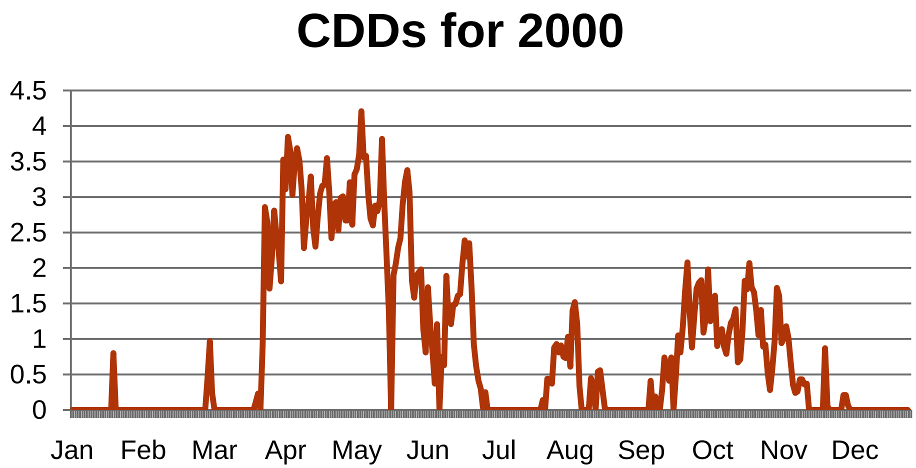


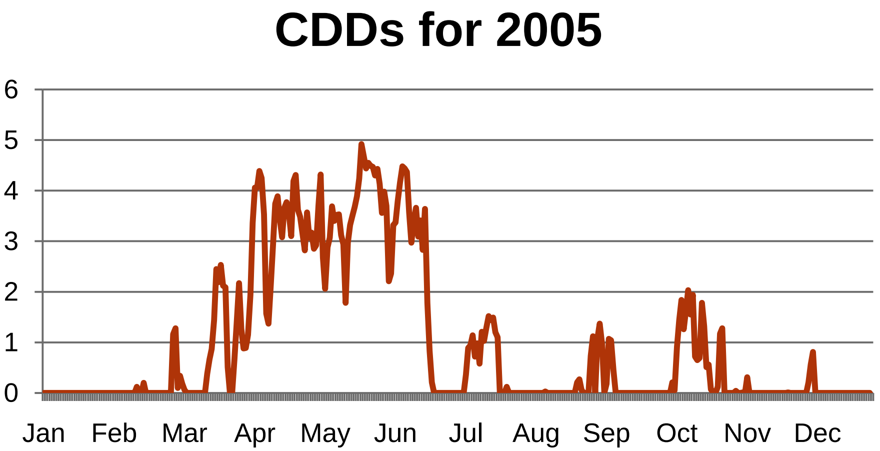


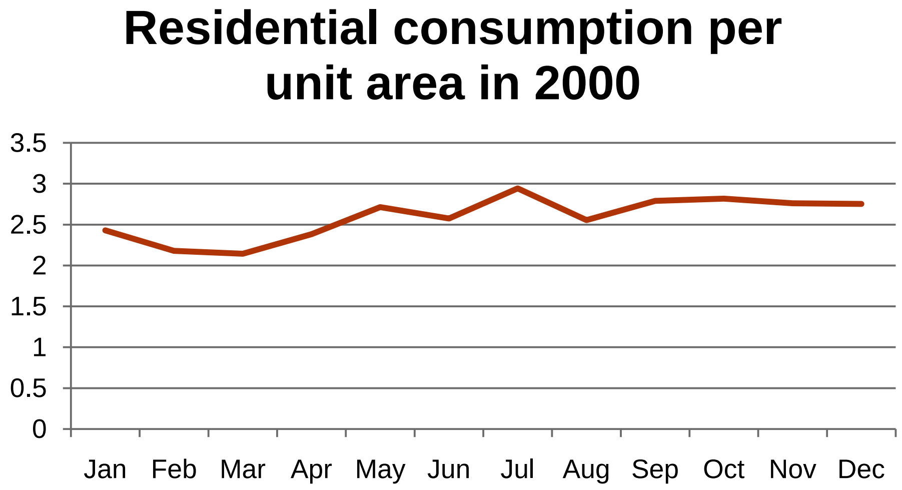


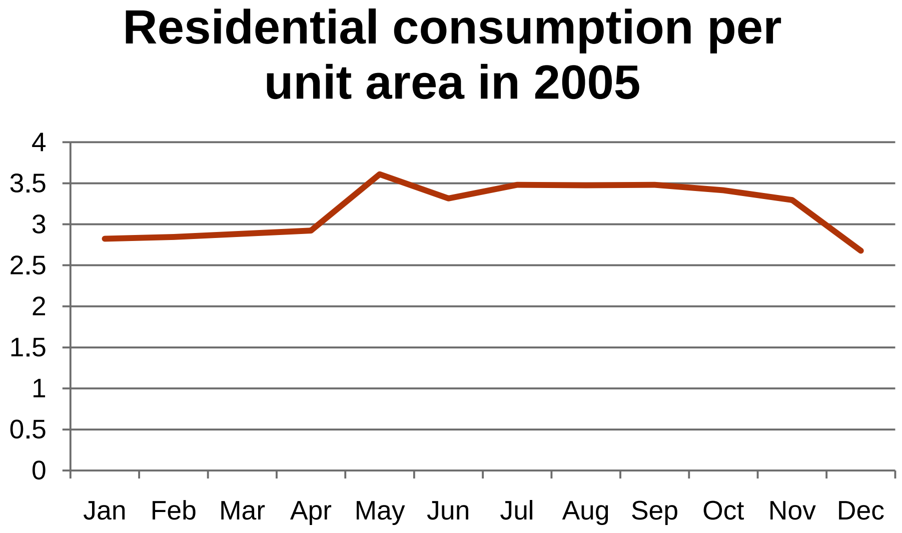


CDD- consumption trends

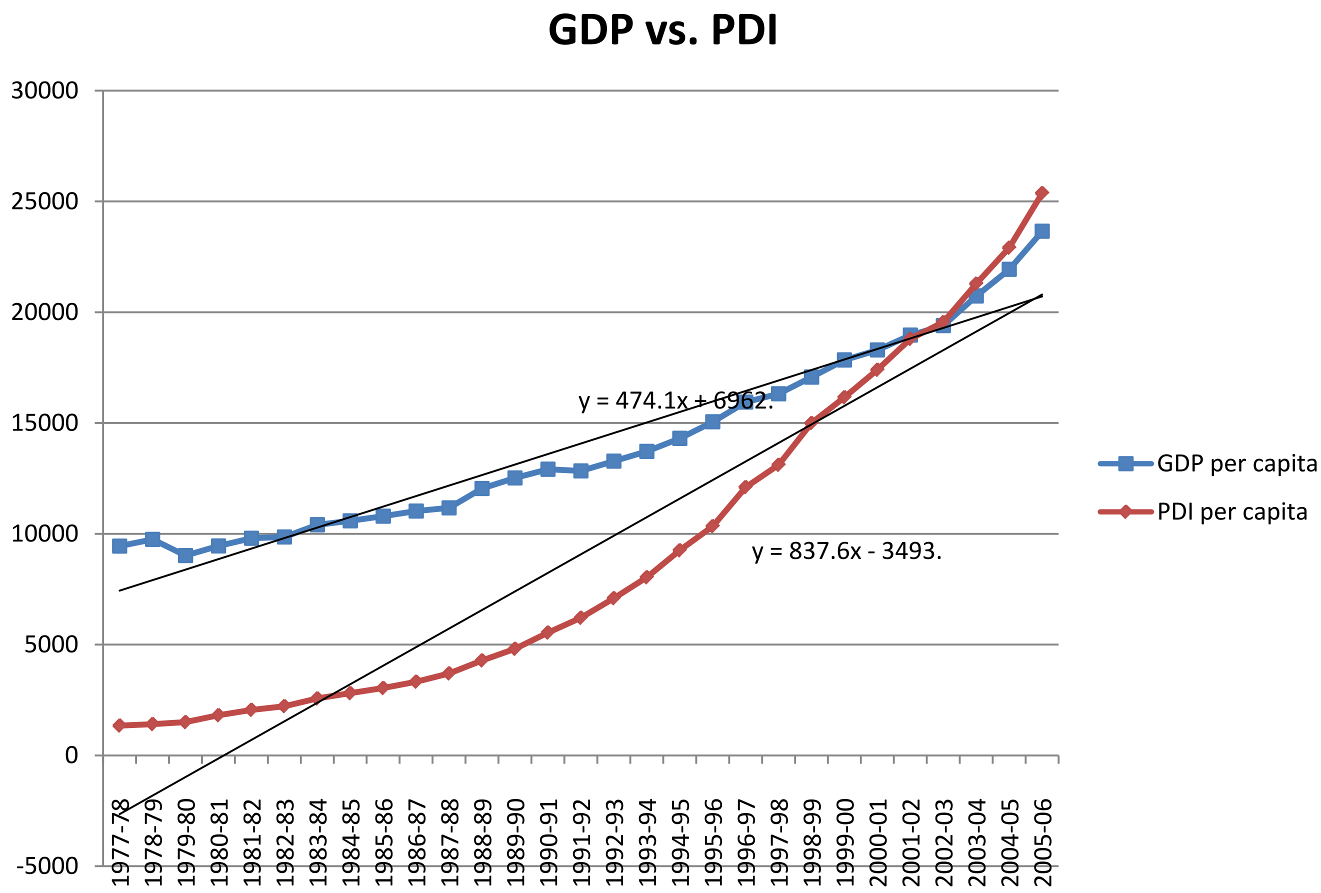








GDP vs. Personal Disposable Income per capita



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Methodology

- For every month, monthly residential consumption per unit area is regressed against PDI/capita and Temperature:

$$E = a\,T + b\,(PDI/capita) + c$$

- E is also regressed against the monthly CDD and PDI per capita
- So we have 12 models in each case
- Similarly two overall models are also built using the entire data-set (one using temperatures and the other using CDDs)

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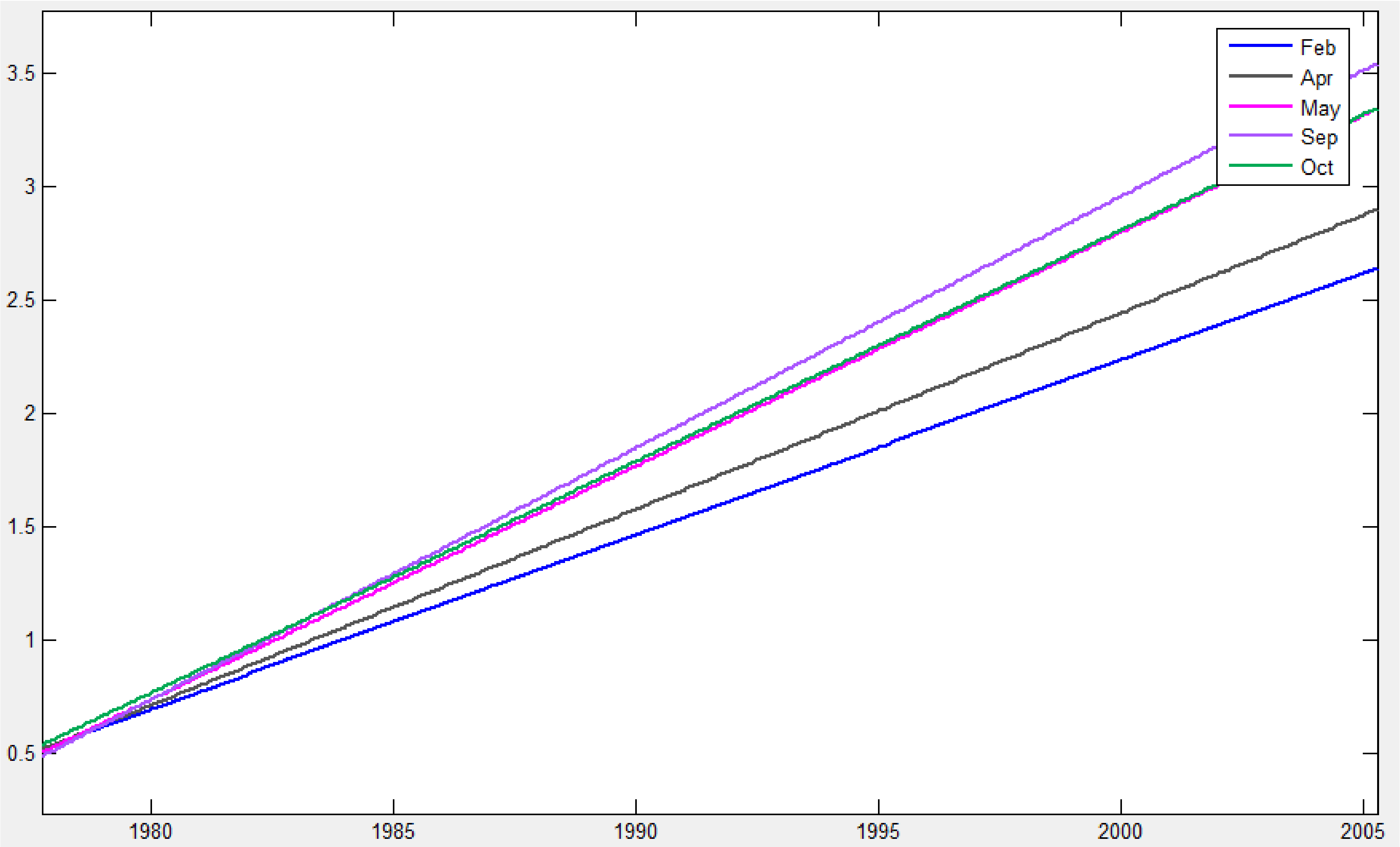
Sample results: *E = aT + b (PDI/capita) +c*

Month	a	b	c	R^2	F -statistics
					(F_{crit} = 0.99 for 1% confidence level)
May	0.0275	0.000112	0.0628	0.94	211.41
Jun	0.0893	0.0001124	-1.6516	0.94	229.88
Jul	0.0010	0.000112	0.81326	0.94	196.53
Aug	0.0958	0.0001066	-1.5096	0.93	171.71
Sep	0.2009	0.0001153	-4.3087	0.94	206.17

Sample results: $E = a(CDD) + b\,(PDI/capita) + c$

Month	a	b	c	R^2	F statistics
					(Fcrit = 0.99 for 1% confidence level)
May	0.00051	0.00011	0.822	0.94	210.84
Jun	0.00191	0.00011	0.732	0.94	216.24
Jul	0.00432	0.00011	0.81	0.94	201.39
Aug	0.00530	0.000107	0.912	0.93	168.10
Sep	0.01206	0.000115	0.811	0.94	198.52
Oct	0.00017	0.000110	0.902	0.94	230.31

Temperature sensitivity of consumption for different months



Overall models

$$E = aT + b\,(PDI/capita) + c$$

a	b	c	R^2	F statistics
				(Fcrit= 0.9905)
0.015085	0.000106	0.4732	0.912	1733.123

$$E = a(CDD) + b\,(PDI/capita) + c$$

a	b	c	R^2	F statistics
				(Fcrit= 0.9905)
3.93E-05	0.000106	0.862	0.9115	1706.553

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We will be working on……

- Including electricity price and number of consumers as possible explanatory variables (data being collected)
- Using IPCC/ TERI scenarios to project energy consumption
- Climate sensitivity of pumping loads
- Relate maximum demand with climate
- Building similar models for different academic and industrial campuses in different cities of India

To conclude……

- Any feedback would be appreciated

- Success of this project would depend on the scale in which it is conducted. We are interested to perform a detailed analysis on a city-wide, state-wide and country-wide basis.

- For this, support from IIT-D, IIT-M, CSE , IITM and other institutes is solicited.

- We are looking for collaborators who would be interested to work with us and help us collect data for different cities and states and make this a successful project

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