Energy Consumption in Residences and Human Comfort

Dr. –Ing. Jyotirmay Mathur
Dean-Academic Affairs
Professor, Mechanical Engineering Department
Centre for Energy and Environment

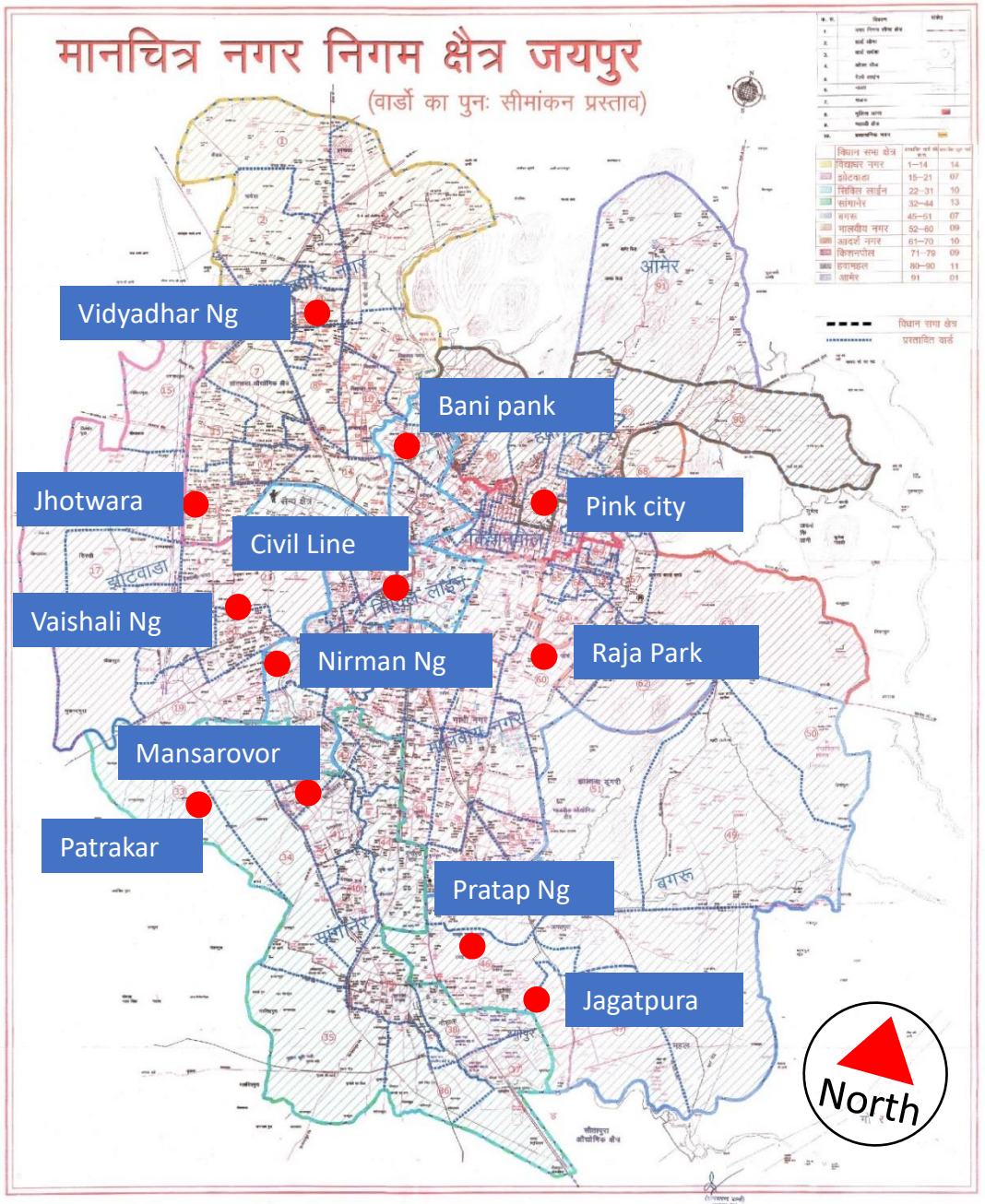
मालवीय राष्ट्रीय प्रौद्योगिकी संस्थान जयपुर
Malaviya National Institute of Technology Jaipur
[AN INSTITUTE OF NATIONAL IMPORTANCE]

What Drives Residential Energy Consumption?

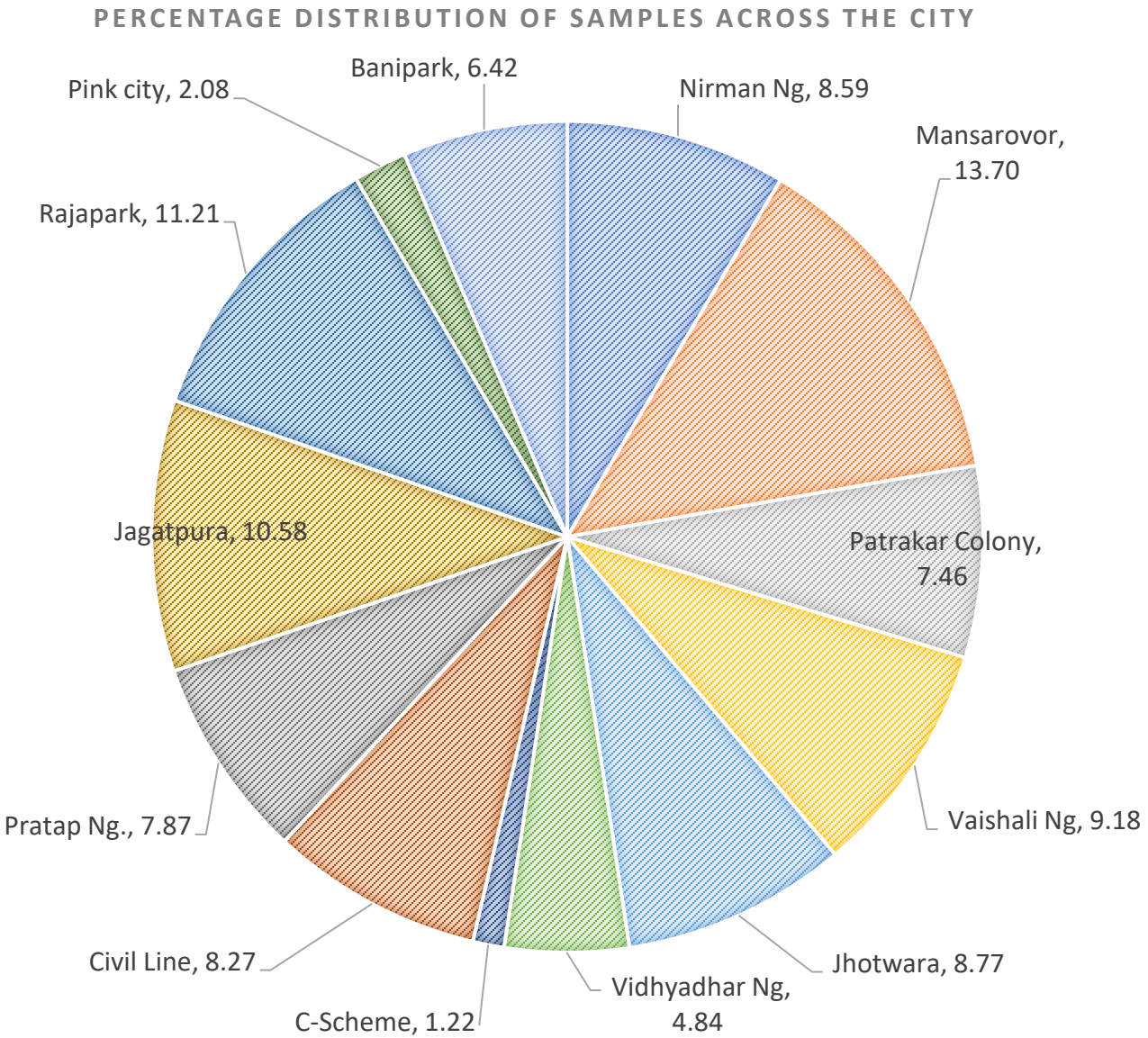
Parameter Name	Type of Variation within the Parameter
Household Income	The user group is classified into 5 income groups
Equipment Ownership	Total wattage of equipment owned by the household
Built up Area	Total built-up area of the dwelling unit
BHK types	Total number of rooms + Kitchen + Hall [1BHK, 2BHK, 3BHK, 4BHK]
Household Size	Number of people living in a household
Build Height	Single Storied, Multi-storied & duplex
Age of the Building	Below 20 yrs., 20-40 yrs., 40 yrs. and above

Some insights through a study of Jaipur City

Distribution of Samples

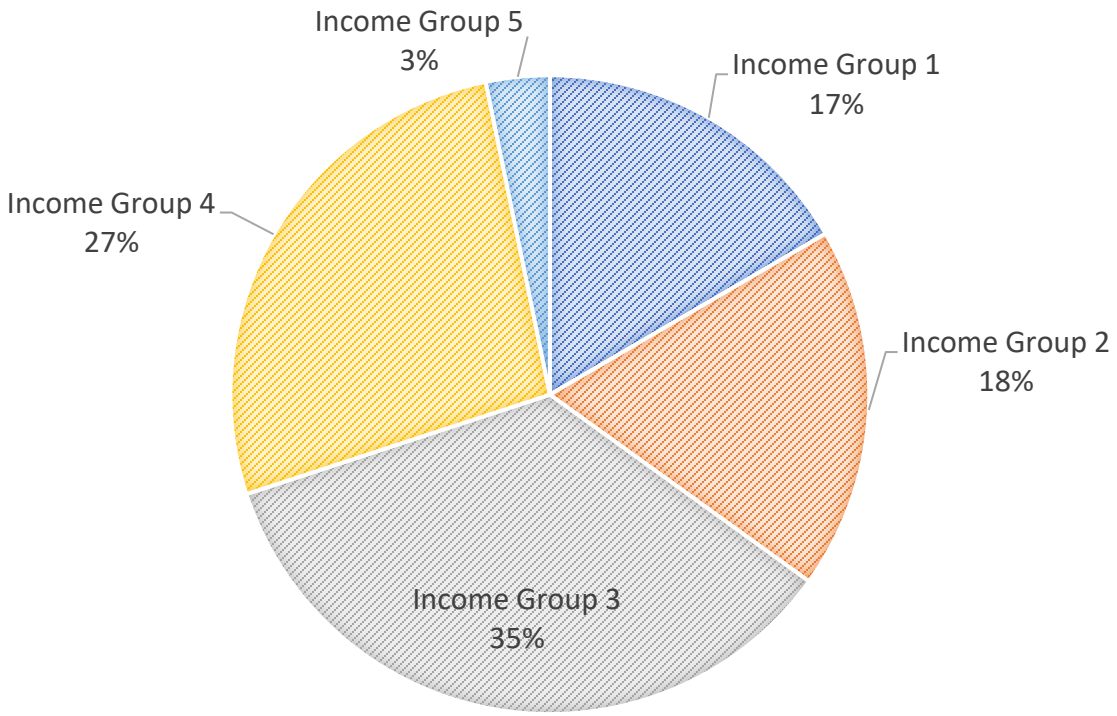


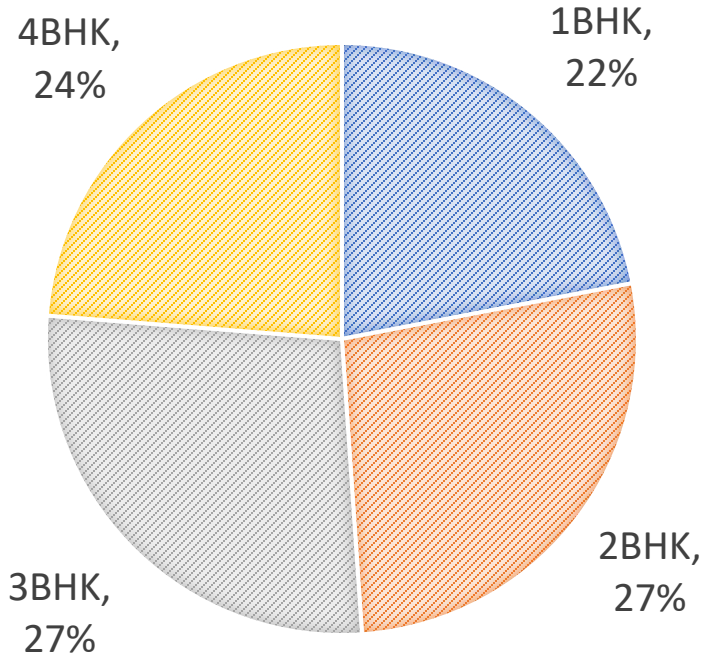
The administrative boundary of Jaipur Municipal Corporation.
[Source: Jaipur Municipal Corporation]



The samples are distributed across the Jaipur.

Percentage Distribution of samples across Income Groups & BHK Types





Group 1: 00- 03 Lakhs / yr
Group 2: 03- 06 Lakhs / yr
Group 3: 06 -12 Lakhs / yr
Group 4: 12 -18 Lakhs /yr
Group 5: 18 Lakhs / yr & above

The income distribution is based on Pradhan Mantri Awas Yojana, income classification.

Sample required	**1536**	**For 95% confidence level in each BHK type**
Samples collected	2345	Assuming 15-20% sample may be lost due to unforeseen circumstances.
1BHK	0526	23 % of the total sample size
2BHK	0601	26 % of the total sample size
3BHK	0622	27 % of the total sample size
4BHK	0578	25 % of the total sample size
Total number of samples after eliminating the inconsistent samples	2327	

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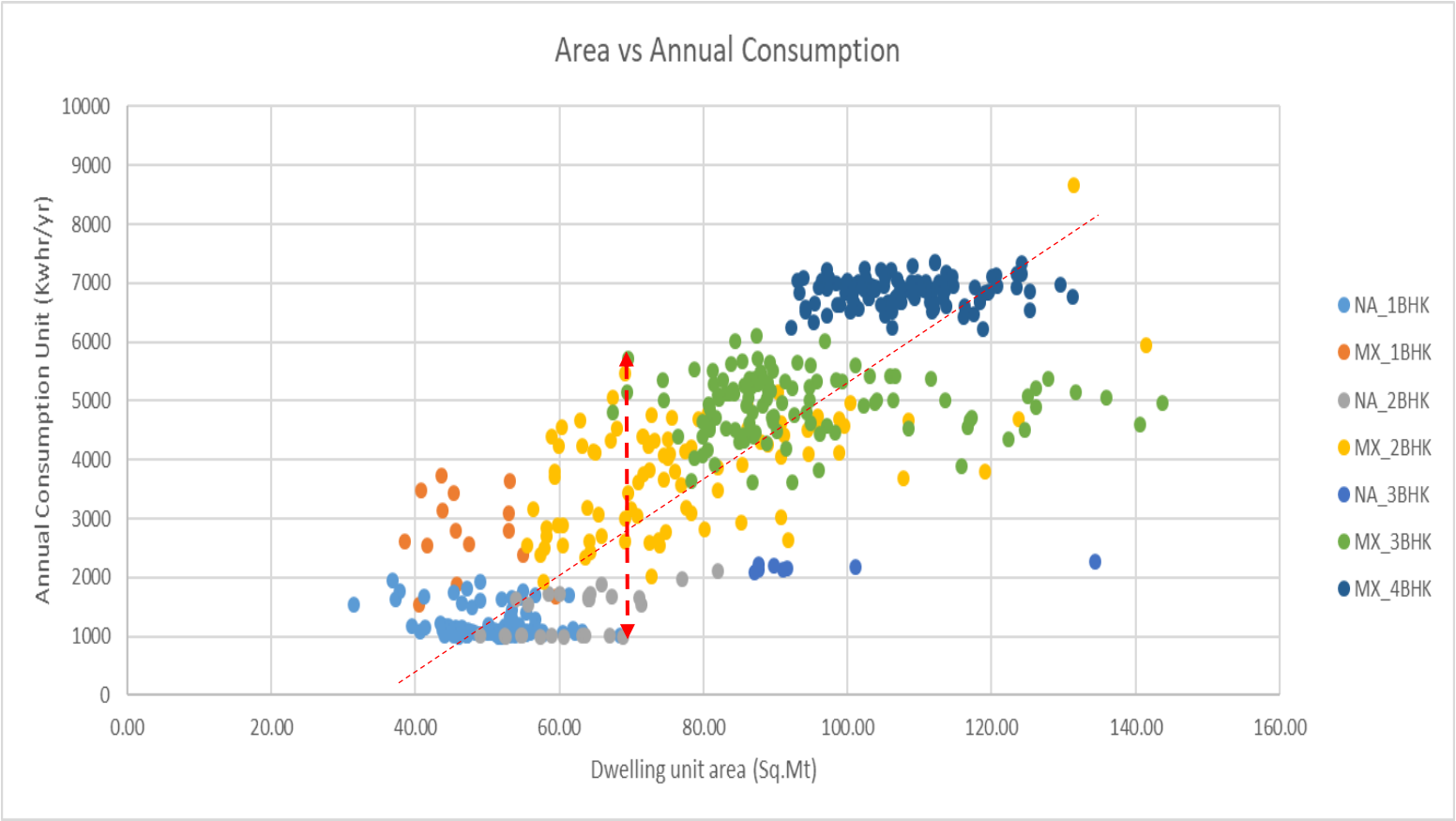
Effect of Dwelling Area on Energy Consumption

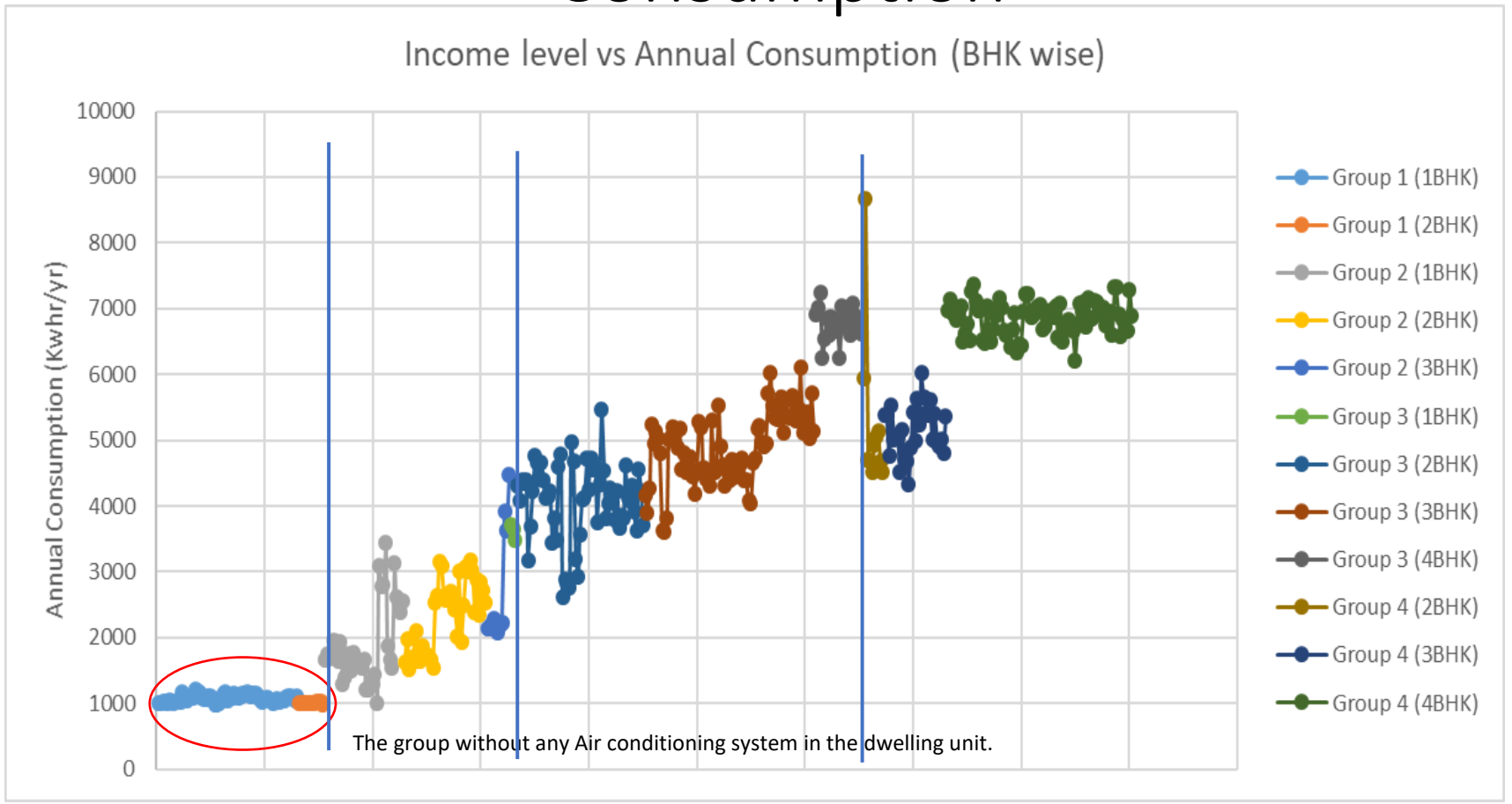


Note:
NA: Non air conditioned unit
MX: Mix mode unit

Building Area/size:

As the size of the building goes up, the consumption gradually goes up too.
However building of same size have also shows very wide range of consumption pattern.
The scatter plot indicates lose relationship between consumption and building size.

Combined Effect of Income and Size on Energy Consumption



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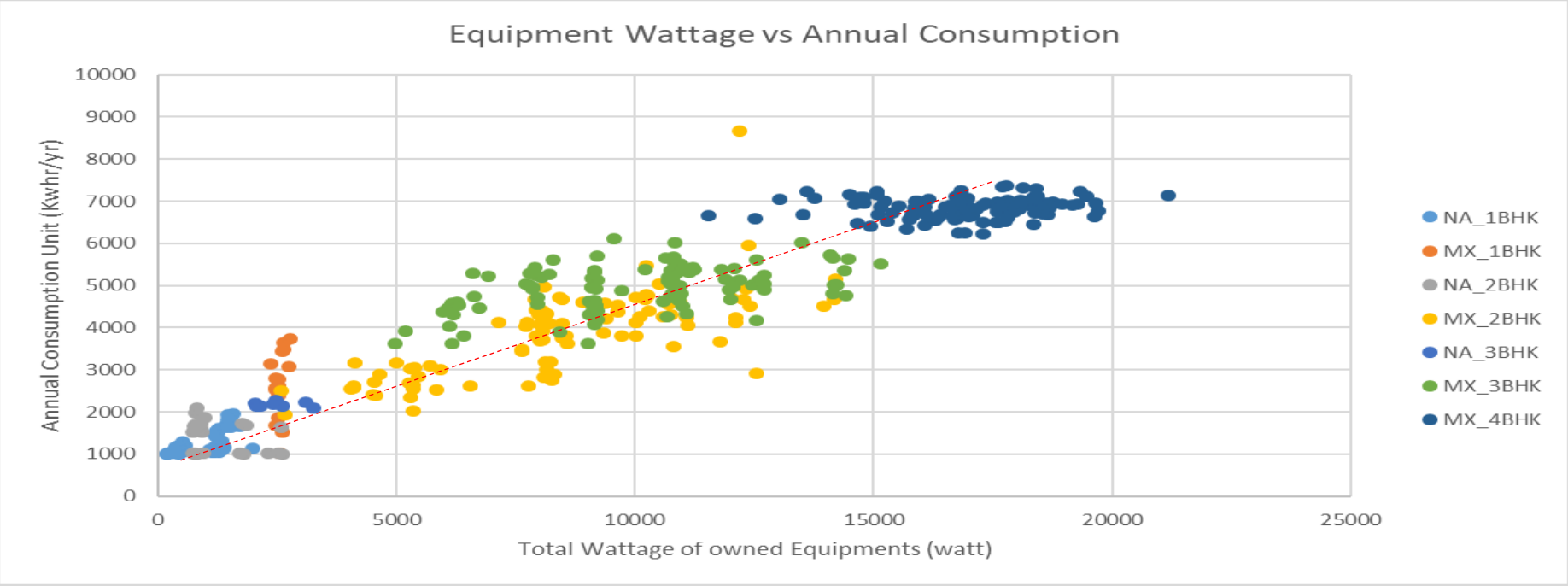
Income Level:

With rising income level the consumption goes up

At times space constraints also limits their consumption.

At large income governs the energy consumption in a household.

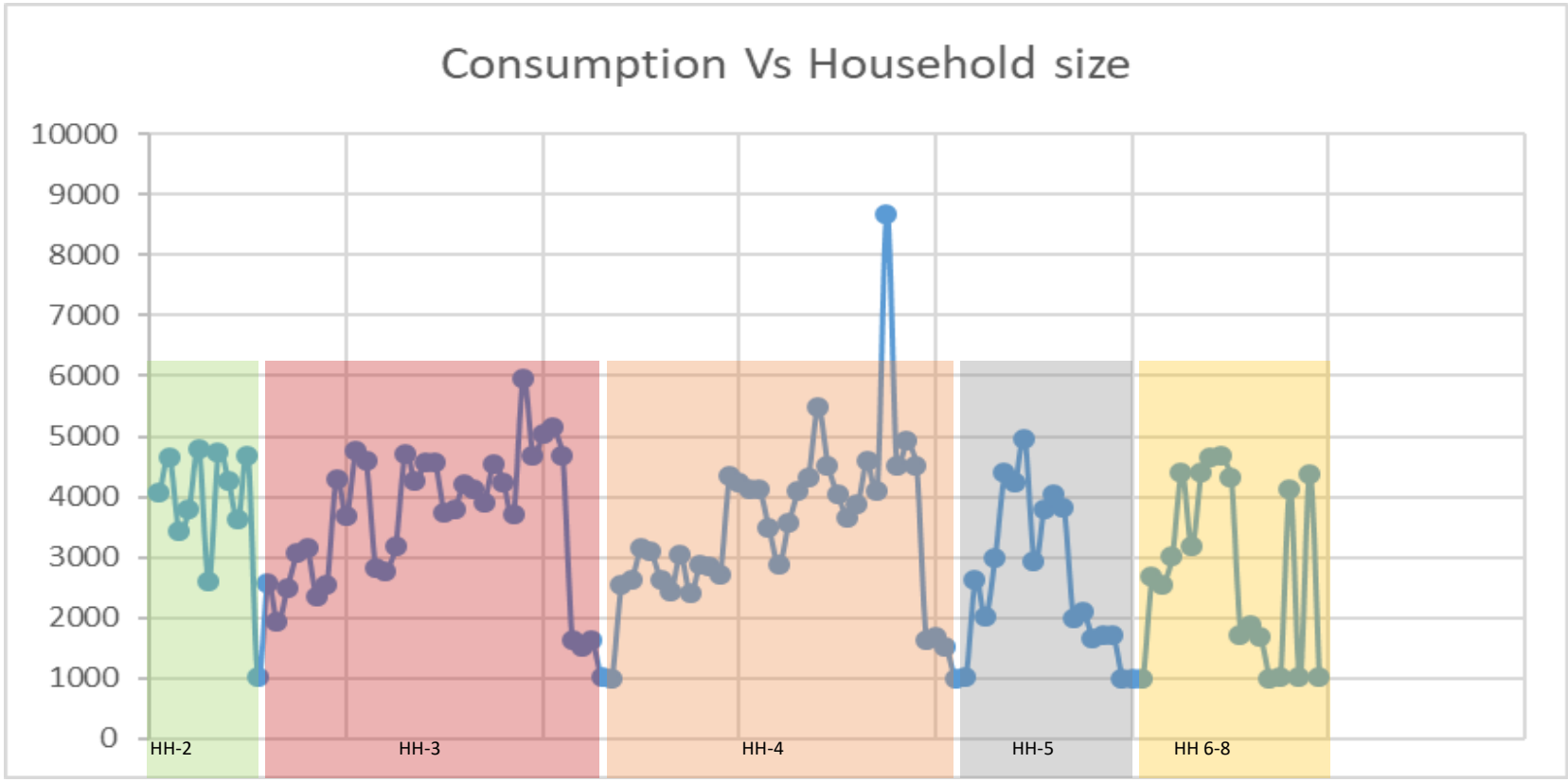


Equipment Ownership:

As the equipment ownership rises the annual consumption goes up gradually.

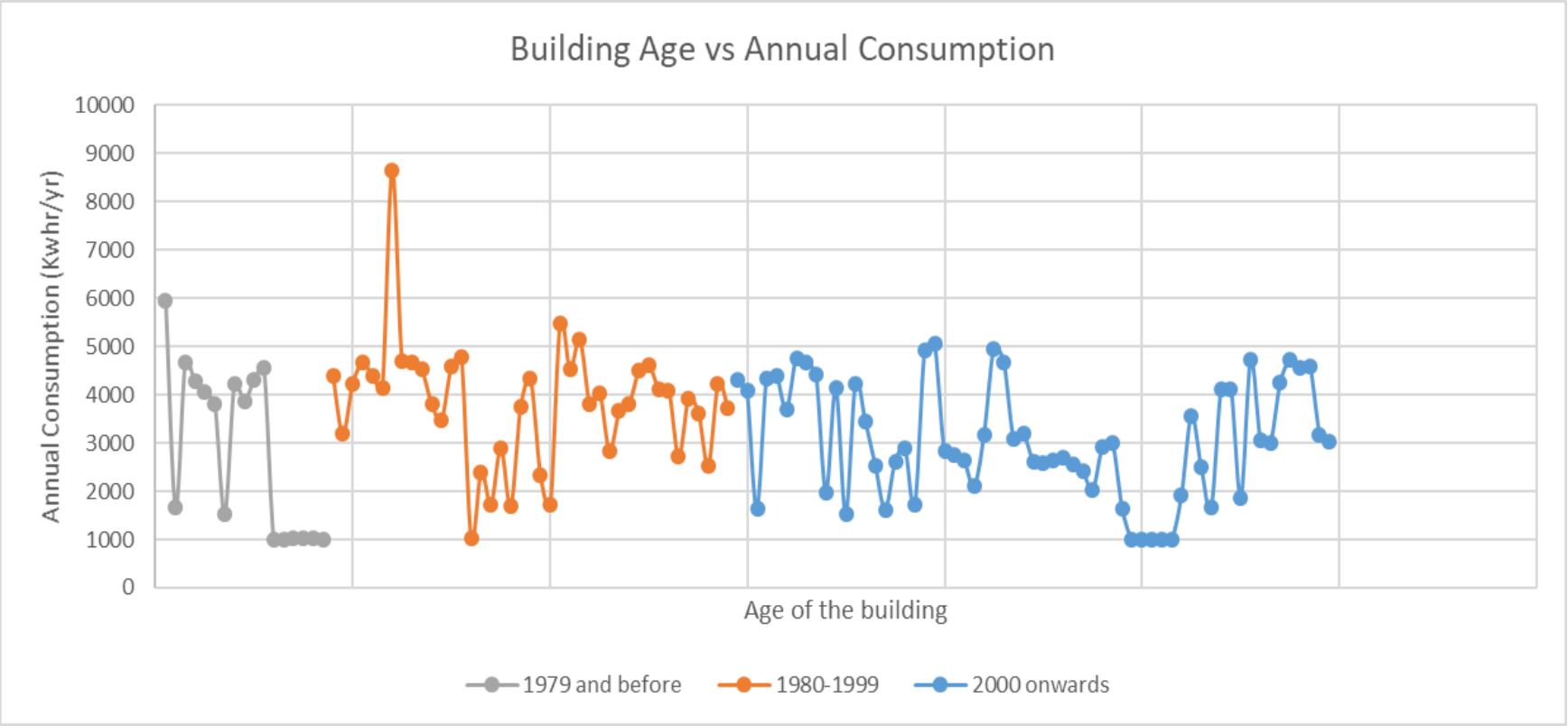
Here the point to be noticed is the gradual growth. Which means despite having the equipment the owner doesn't use it all the time, it certainly depends on its capacity to pay for the reoccurring expenses.

Effect of Household Size on Energy Consumption



Household Size (HH) –
In low income houses there are examples of 6-8 people living in a 2BHK unit with very low consumption.
Some 2BHK units with higher income levels have found to consume more energy.

Effect of Building Age on Energy Consumption

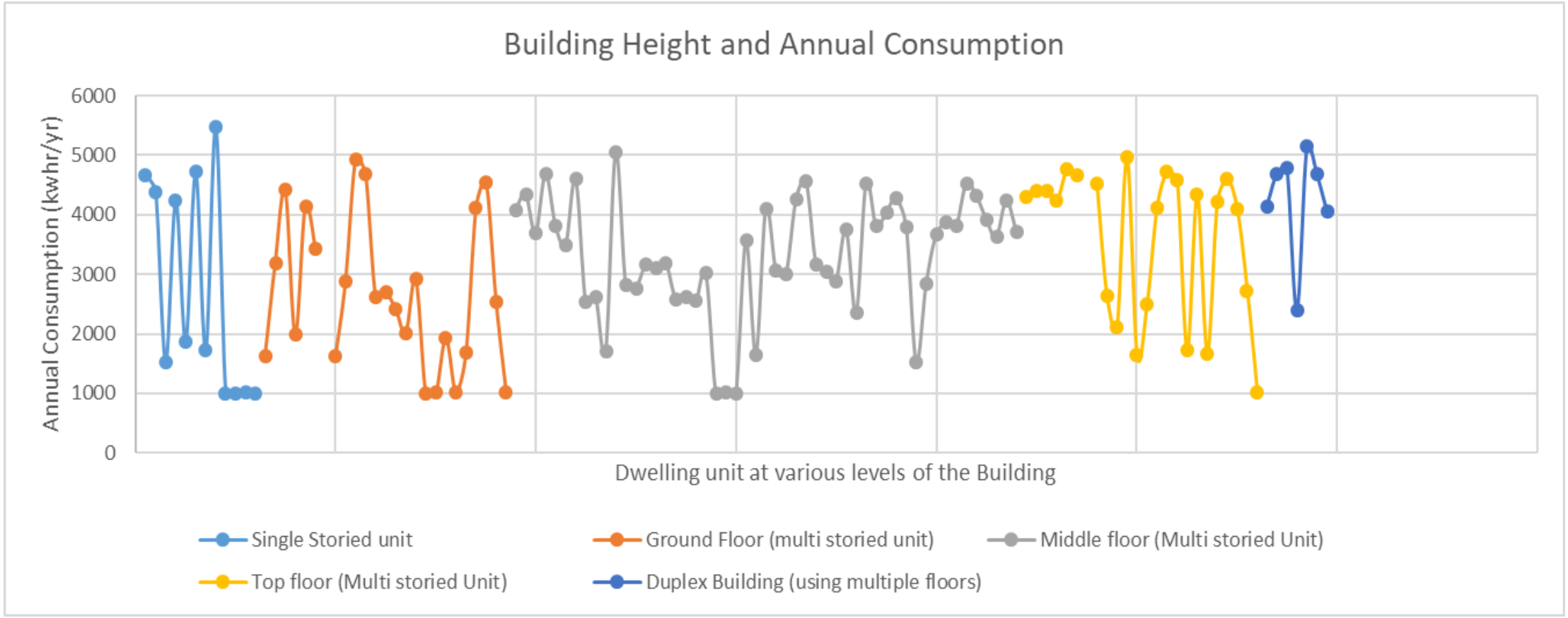


Building Age:

The age of surveyed buildings has wide range (up to 100 years).

The graph indicates no clear relationship between energy consumption and building age.

Effect of Building Height on Energy Consumption



Building heights:
The graph doesn't indicate any clear relation ship between the building heights and energy consumption.

Building form (attached/detached):
The graph does not show any relationship between building form and energy consumption.

Principal Component Analysis (PCA)

	Floor Level	BHK Type	Age of Building	Household Size (HH)	HH/Area	Income Class	Built-up area	Equipment Load	Load/Area	EPI	Annual Consumption
Floor Level	1.00	0.16	-0.29	0.12	-0.04	0.14	0.13	0.18	0.12	0.10	0.18
BHK Type	0.16	1.00	-0.24	0.20	-0.52	0.79	0.55	0.88	0.78	0.66	0.89
Age of Building	-0.29	-0.24	1.00	-0.10	0.11	-0.28	-0.11	-0.29	-0.32	-0.28	-0.28
Household Size (HH)	0.12	0.20	-0.10	1.00	0.60	0.09	0.02	0.15	0.13	0.12	0.15
HH/Area	-0.04	-0.52	0.11	0.60	1.00	-0.55	-0.50	-0.52	-0.44	-0.30	-0.53
Income Class	0.14	0.79	-0.28	0.09	-0.55	1.00	0.59	0.89	0.84	0.75	0.89
Builtup area	0.13	0.55	-0.11	0.02	-0.50	0.59	1.00	0.57	0.38	0.24	0.56
Equipment Load	0.18	0.88	-0.29	0.15	-0.52	0.89	0.57	1.00	0.94	0.76	0.94
Load/Area	0.12	0.78	-0.32	0.13	-0.44	0.84	0.38	0.94	1.00	0.86	0.88
EPI	0.10	0.66	-0.28	0.12	-0.30	0.75	0.24	0.76	0.86	1.00	0.85
Annual Consumption	0.18	0.89	-0.28	0.15	-0.53	0.89	0.56	0.94	0.88	0.85	1.00
Ranking		**2A**			**5**	**2B**	**4**	**1**	**3**		

Target Variables

A correlation matrix was prepared for all the parameters shortlisted in the previous section.

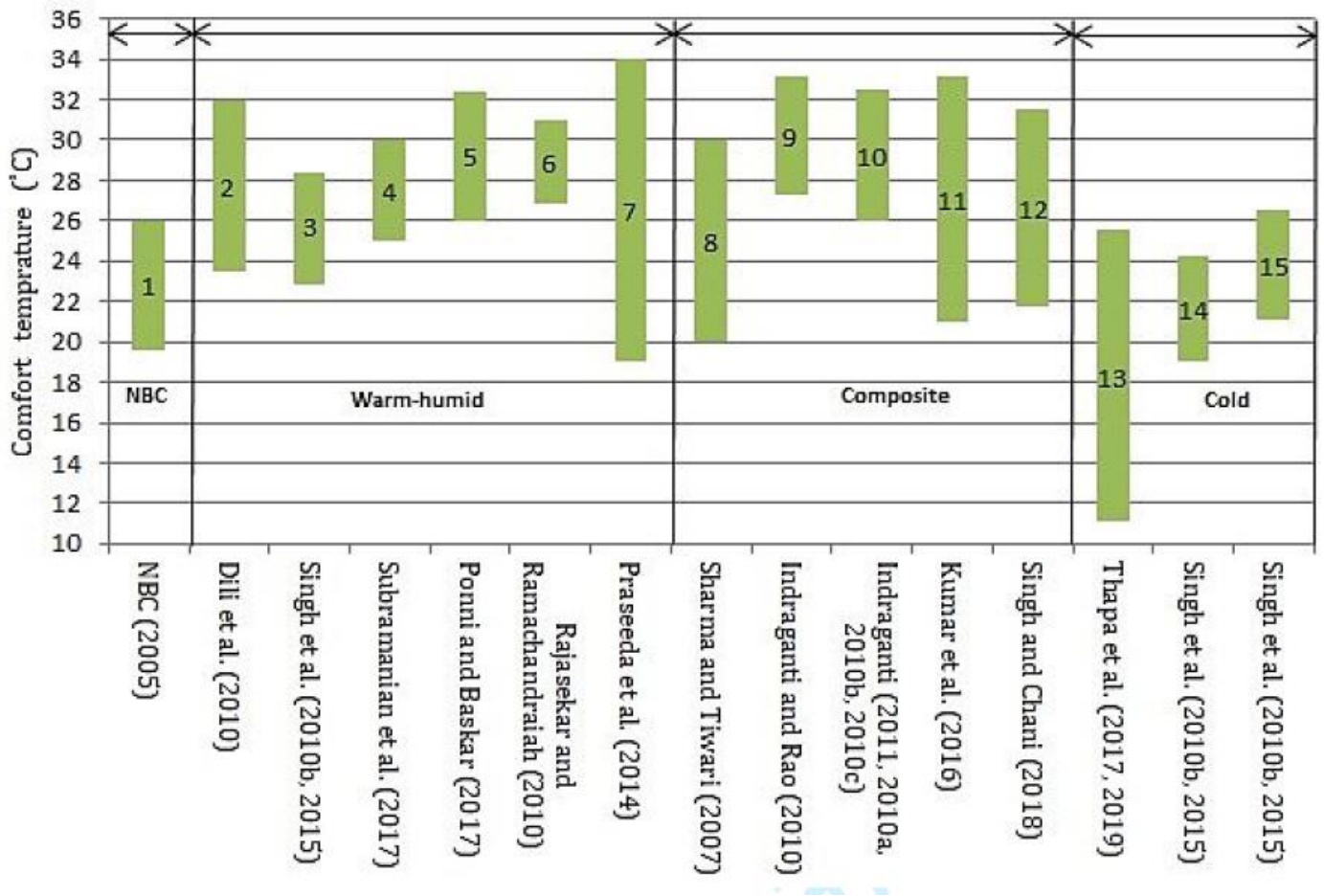
0	0.40 – 0.69	0.70 – 0.89	0.90 - 1
Weak	Moderate	Strong	Very Strong

KEY FINDINGS

Equipment ownership, BHK type, Income Class, Load/Area, Built-up area and Household /Area have strong correlation with energy consumption.

Some insights through thermal comfort studies!

Meta-study of thermal comfort studies

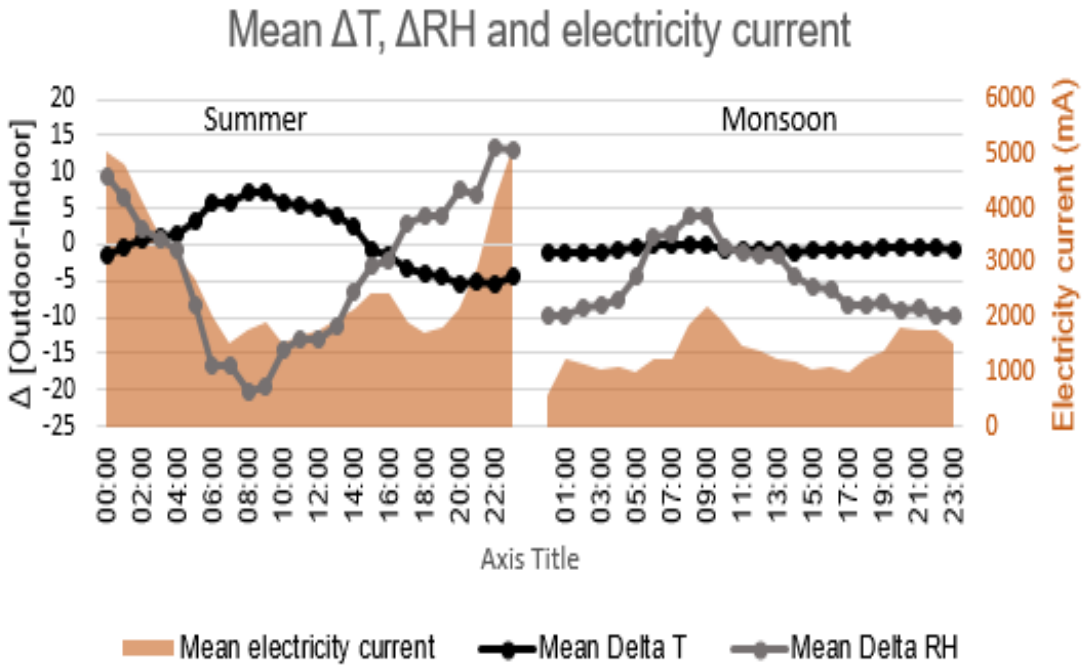


Comfort temperature range obtained by different studies in Indian residential buildings.

Relationship of residential AC use with indoor temperature and relative humidity

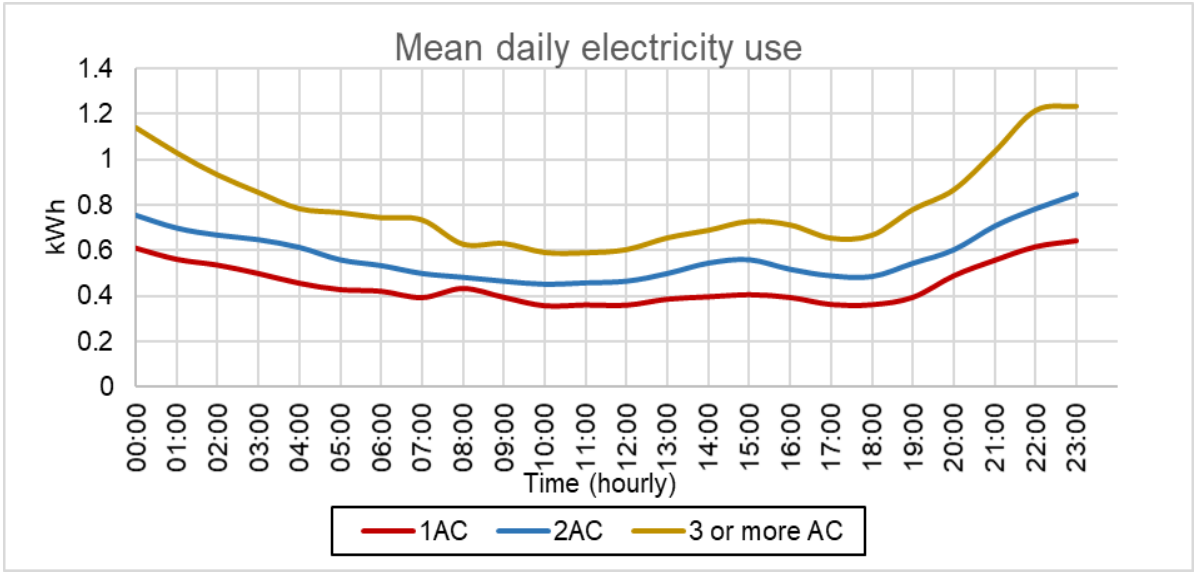
- In summer, as delta T decreased, delta RH increased, more electricity current was used especially during night time from 8:00pm to 2:00am - likely to be for AC use.

- Threshold indoor temperature & RH band at which AC was turned on
  - Summer - Temperature **29-32 °C** and RH **36-39%**
  - Monsoon - Temperature **26-29°C** and RH **59-62%.**



Variation in daily and peak electricity use by extent of AC ownership

- Households with 3 or more AC units had 2x daily, seasonal and annual electricity use as compared to 1 AC households.
- Similar patterns of AC use observed in the summer and monsoon seasons, although magnitude and peak usage period differed by extent of AC ownership.
- Electricity use during the peak period for households with 1 or 2 AC units was 4.6 kWh and 6.3 kWh for households with three or more AC.
- Peak period of use of AC was recorded during night-time from 8pm-2am.



Households with	Attribute	Summer	Monsoon
1 AC unit	Peak period	9 pm-3 am	10 pm-3am
	Electricity use during peak	4.6 kWh	2.9 kWh
2 AC units	Peak period	8 pm-2 am	8 pm-2 am, 3 pm-4 pm
	Electricity use during peak period	4.6 kWh	4.4 kWh
3 or more AC units	Peak period	8 pm-2 am	8 pm-2 am
	Electricity use during peak period	6.3 kWh	5.9 kWh

Common adaptive actions in residential environment

Conditioned

- Adjust temperature
- Use blanket if feeling cold
- Adjust fan speed
- Adjust blinds/curtains

Un-conditioned

- Adjust fan speed
- Adjust window opening
- Adjust clothing
- Adjust blinds/curtains
- Tolerate if nothing works

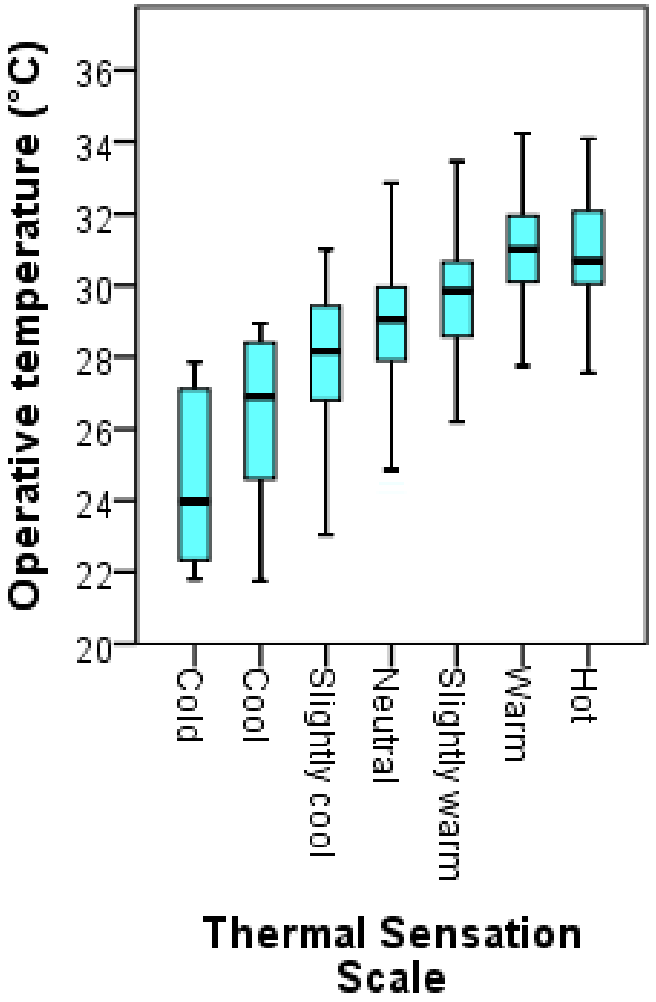
Is temperature the main driver for window operation?

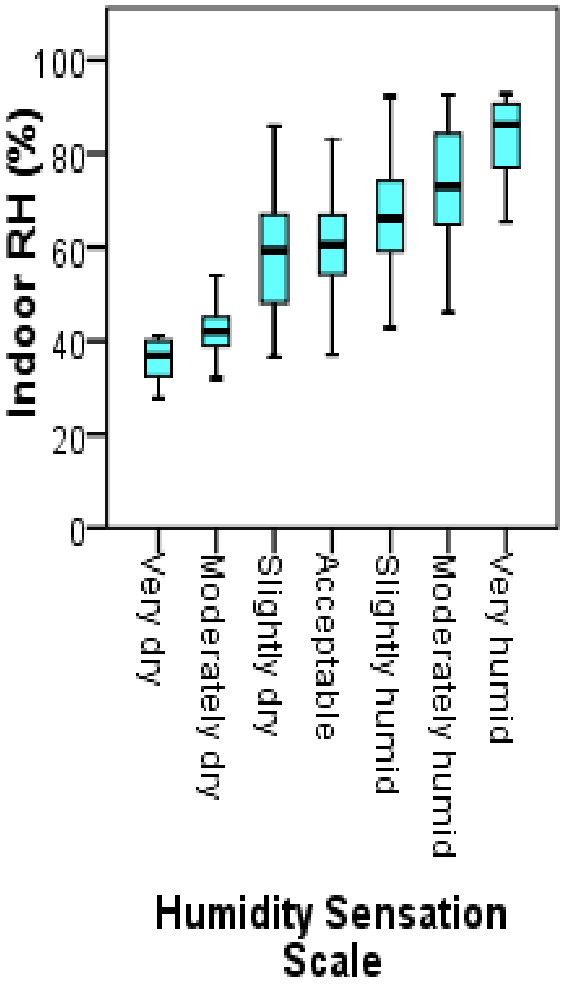
Situation	Adaptive action
What do you do when you feel low?	Open the window, put off the curtains
What do you do when there is too much noise coming from outside?	Close the window
What do you do when there is too much pollution outside?	Close the window
What do you do when feeling suffocated?	Open the window
What do you do when there are too many mosquitoes outside?	Close the window
What do you do if there is a safety/theft issue:	Close the window
What do you do when there is glare in room?	Pull the curtains/blinds
What do you do when mosquitoes are more	Close the window

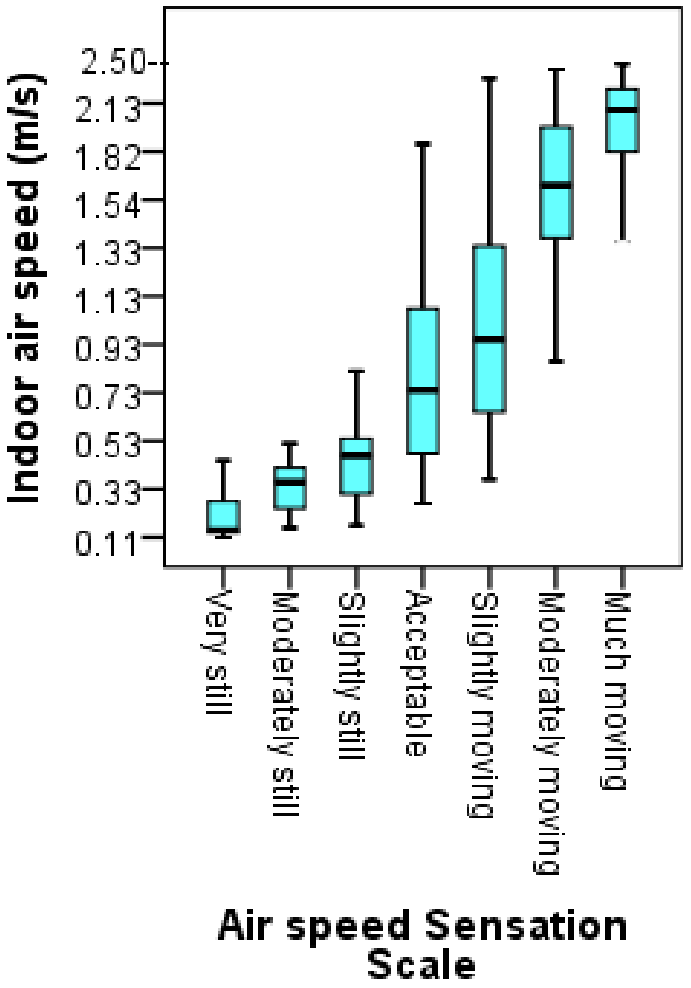
Key issue in study of adaptive actions

- Most adaptive actions are taken NOT due to one single cause
- Multiple adaptive actions are taken together in **AC homes**: temperature, clothing, fan in very few cases
- More multiple adaptive actions are taken together in **non-AC homes**: windows, curtains, fan, clothing, expectation
- Making multi-variate analysis a necessity for truly reflecting adaptive model

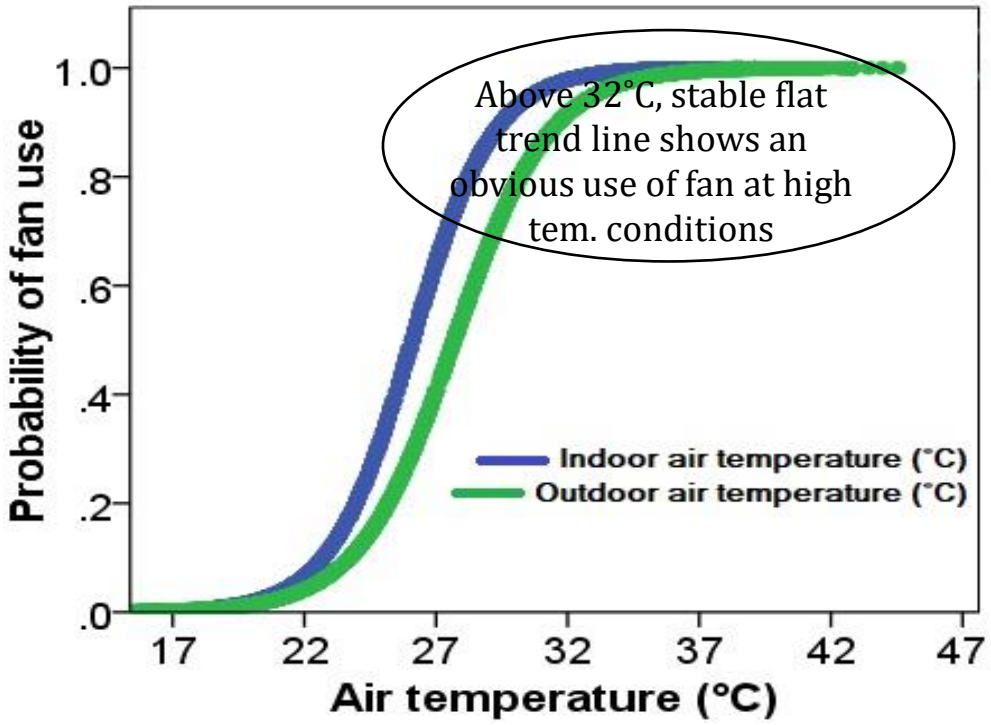
Wide variation in thermal comfort data (4658 samples)

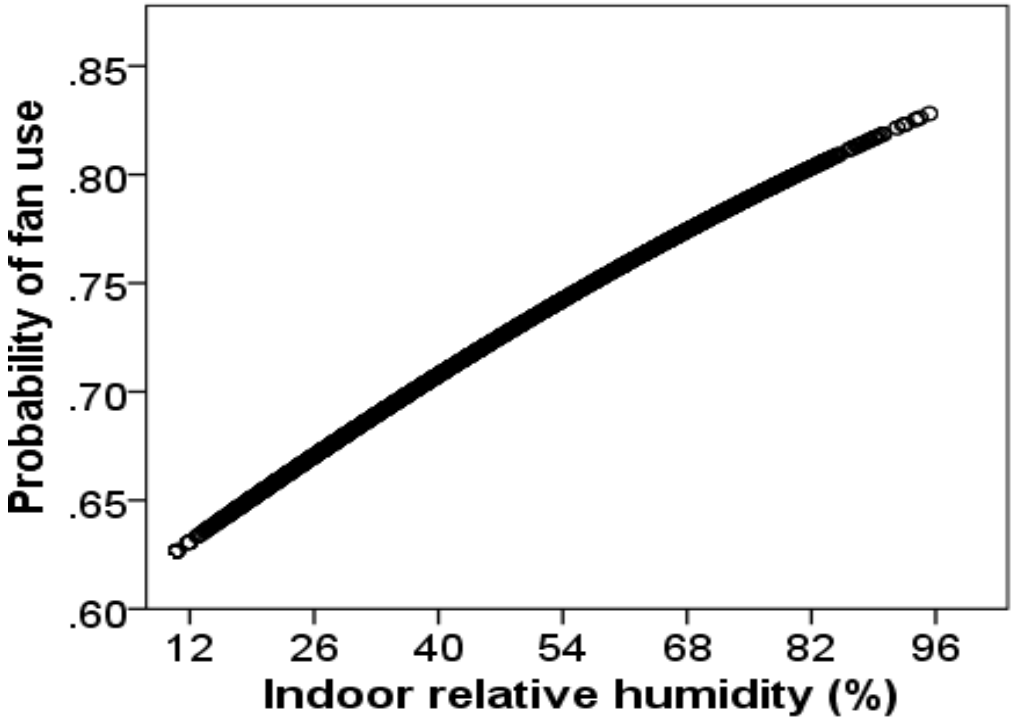






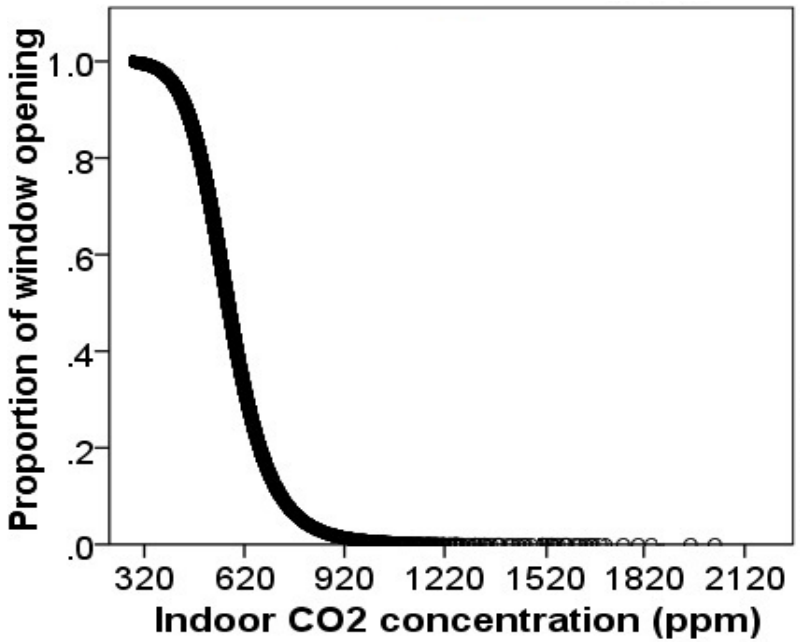
When do people use fan?

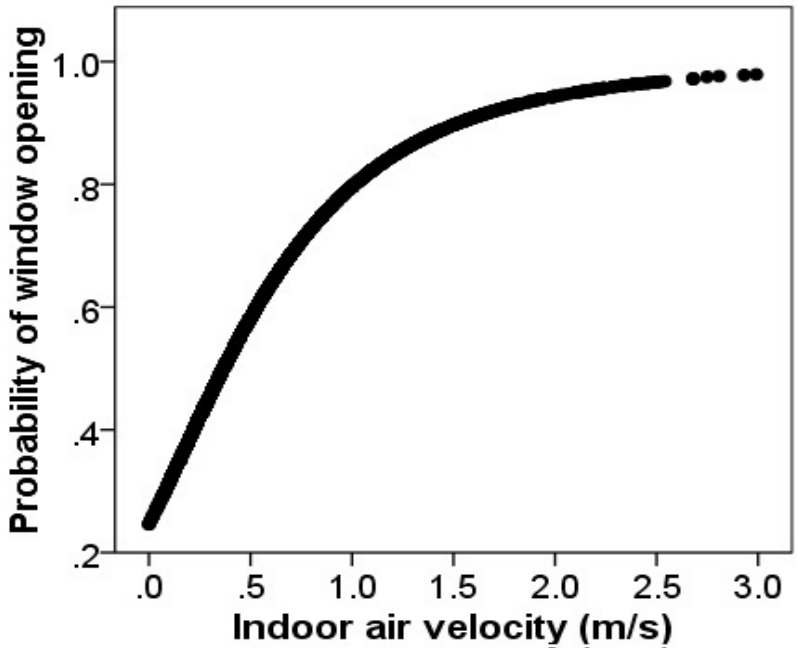


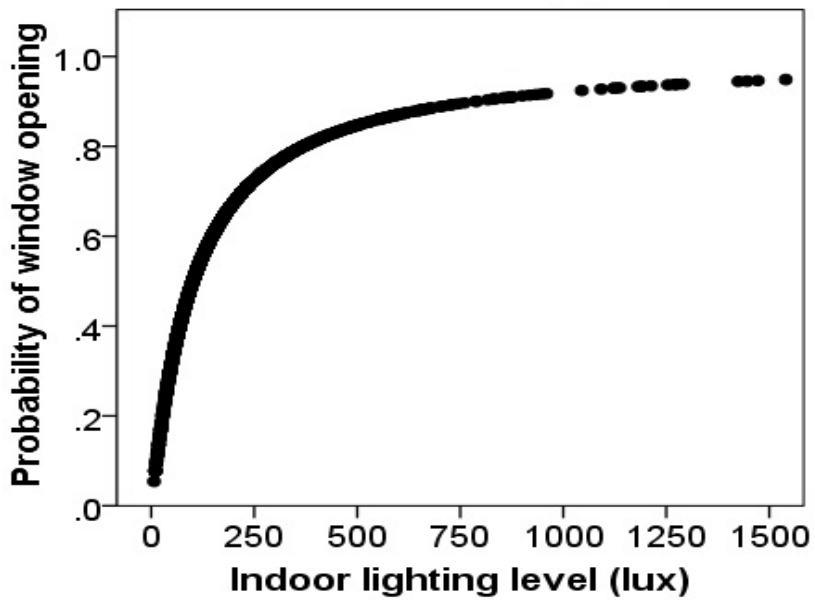


- Subjects use of fan is based on the combined effects of temperatures and relative humidity.
- Therefore, a good **adaptive comfort model should directly include relative humidity**

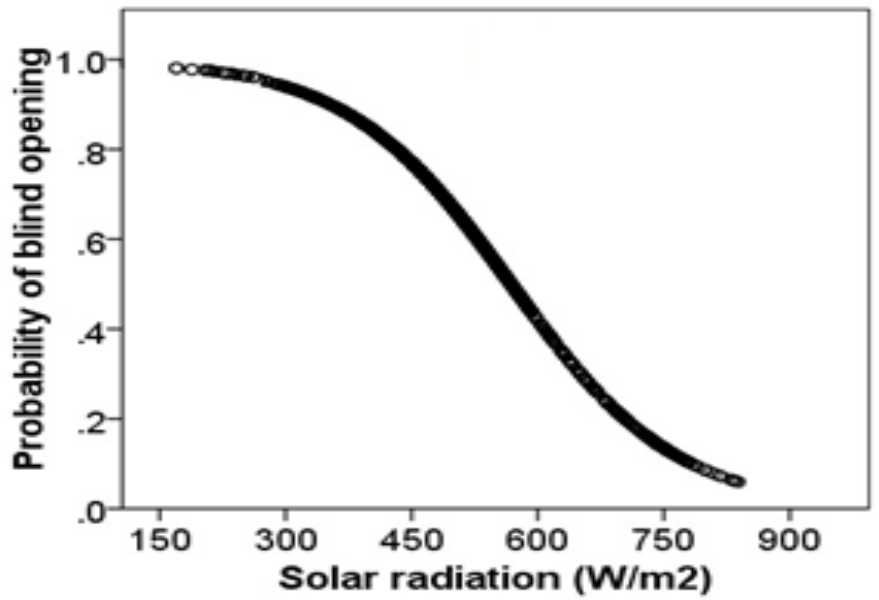
Window opening behaviour (Cont……)

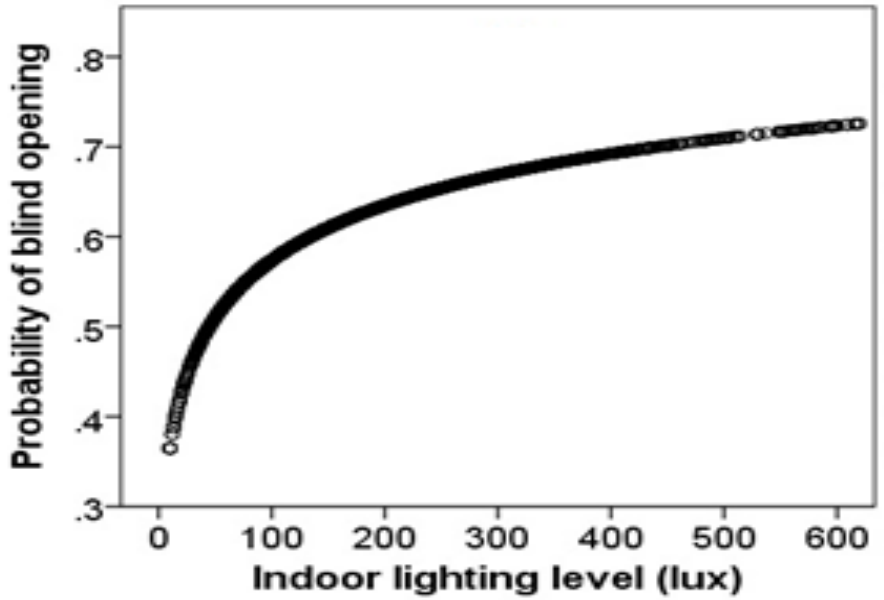


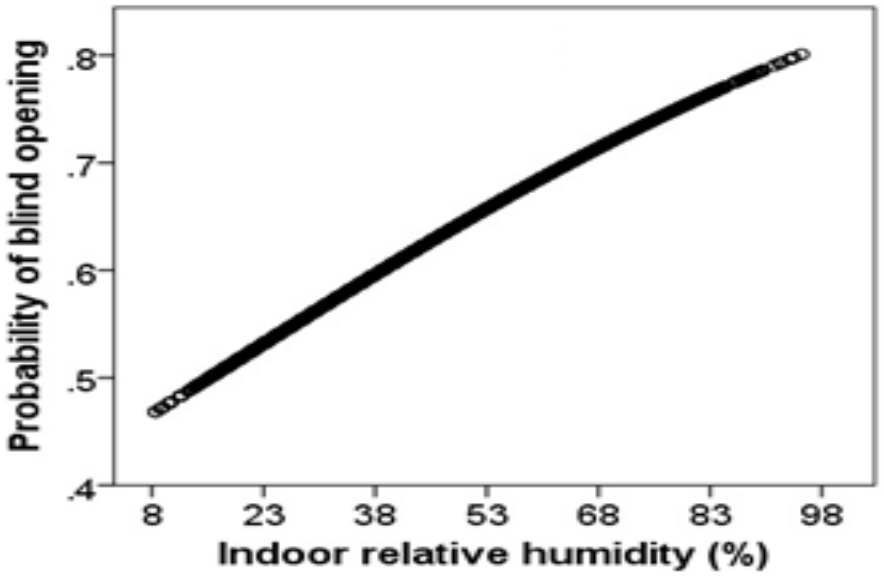


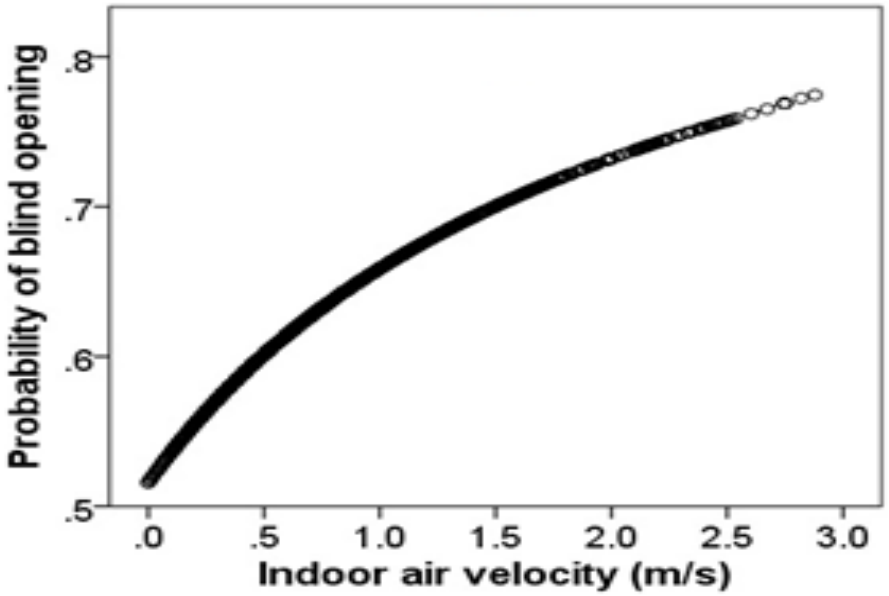


Use of Blind/curtain

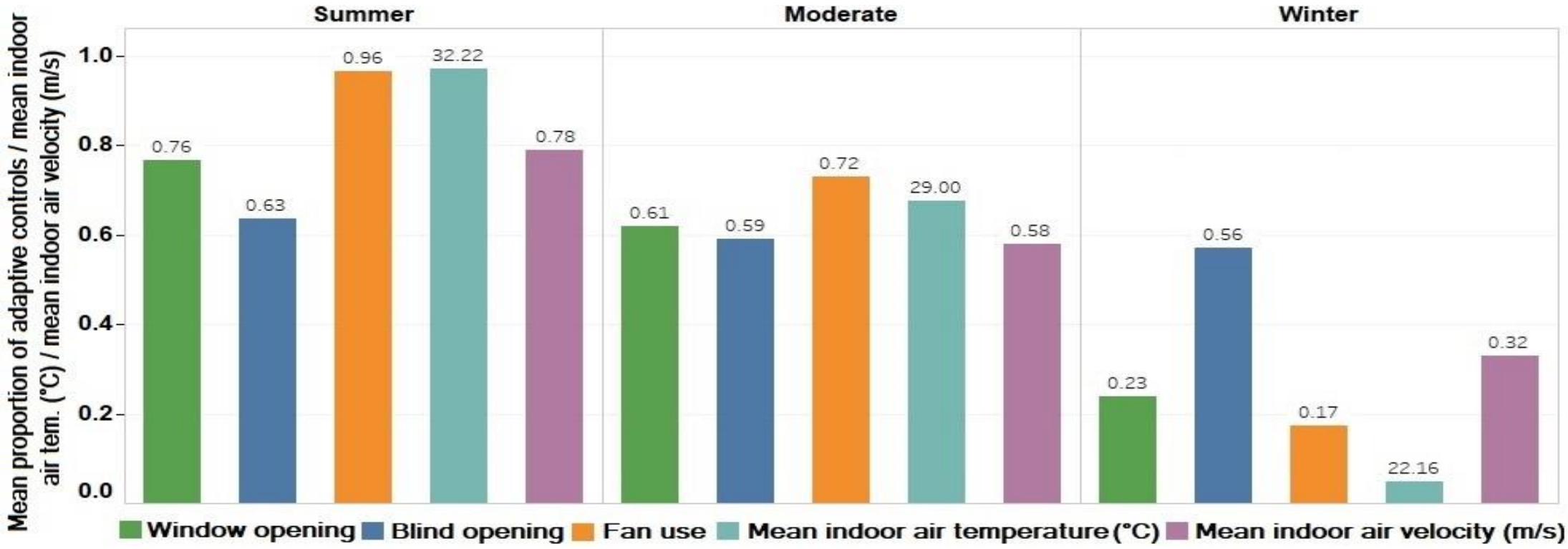








Use of adaptive controls across the seasons



Conclusion

- Residential Energy Consumption depends upon combination of parameters
- EPI (kWh/sqm) needs to be adjusted against them before concluding status of energy efficiency!
- Thermal adaptation is not a univariate problem!!
- Univariate adaptive equations need to be read with their qualifiers/applicability limits

Thanks!!