NEED FOR CENTRALIZED COOLING SYSTEMS IN HIGH DENSITY MASS HOUSING IN INDIA

Towards smart energy policy in residential communities

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Centralized cooling systems in high density mass housing in the developing world

Agenda

Background- energy scenario in India in international context, affordable housing sector in India

Cooling need in residential communities from household primary surveys

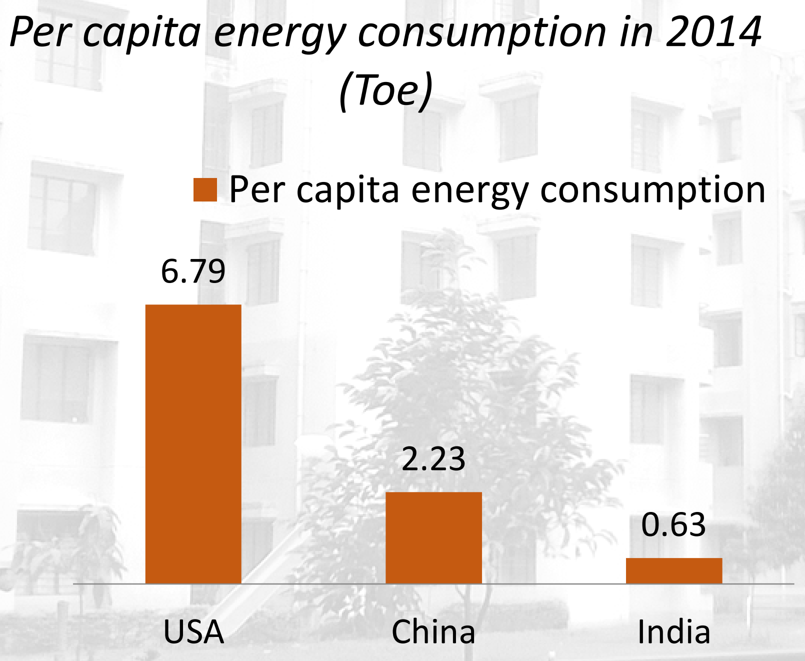
Current scenario of unitized AC and district cooling as an alternative low exergy cooling scenario

Key benefits of centralized cooling

Institutional mechanisms acting as enablers of district cooling

Summary of conclusions and future work

Background: Energy scenario in India in international context

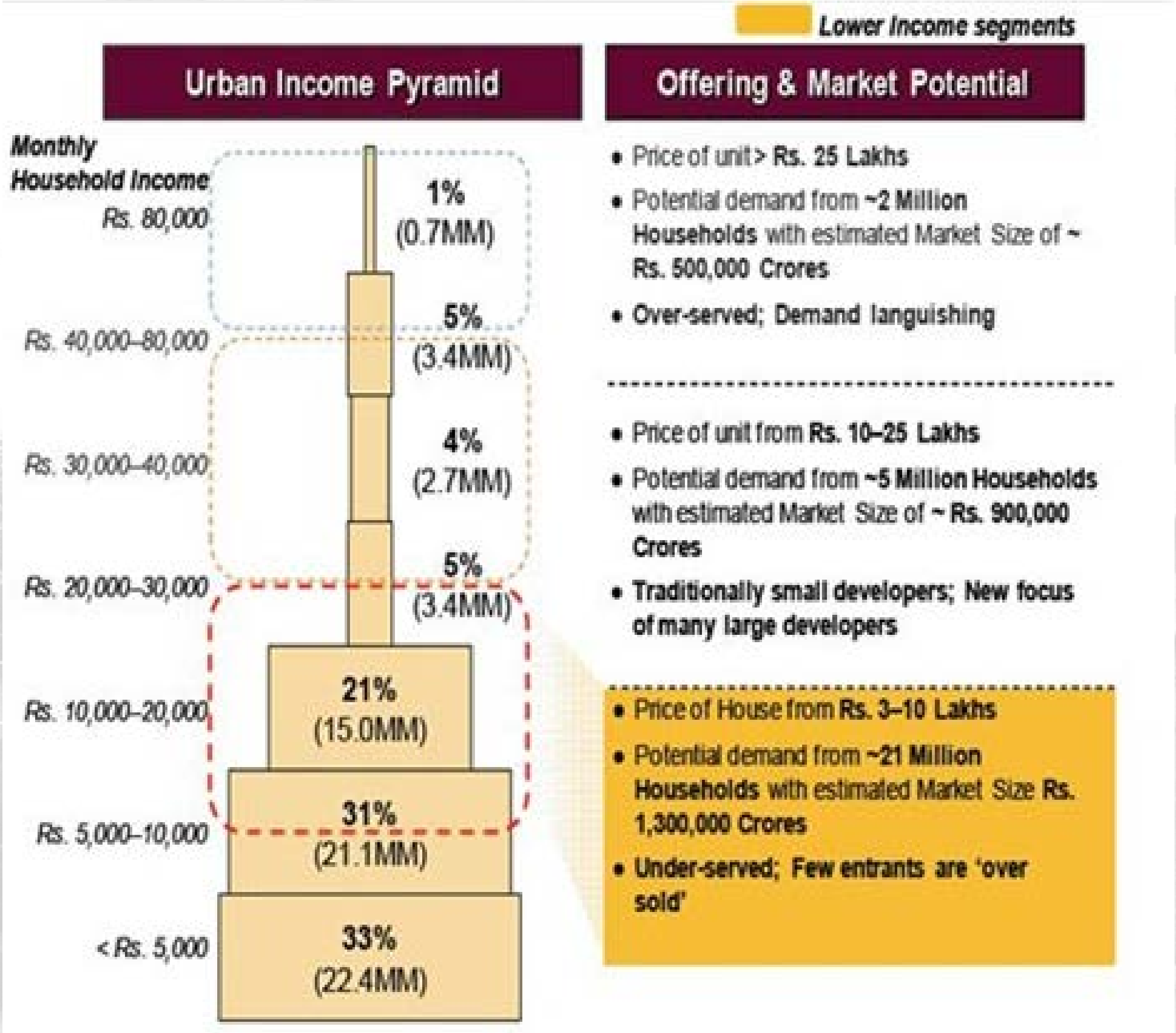


Source- World Bank, 2014

- **Per capita energy consumption is expected to increase rapidly** in the coming decades

- Presently, India is heavily dependent on fossil fuel imports which meet 70 percent of the country's energy demands (IEA 2012)- **pushes India to geopolitical risk** and **international energy market volatility**.

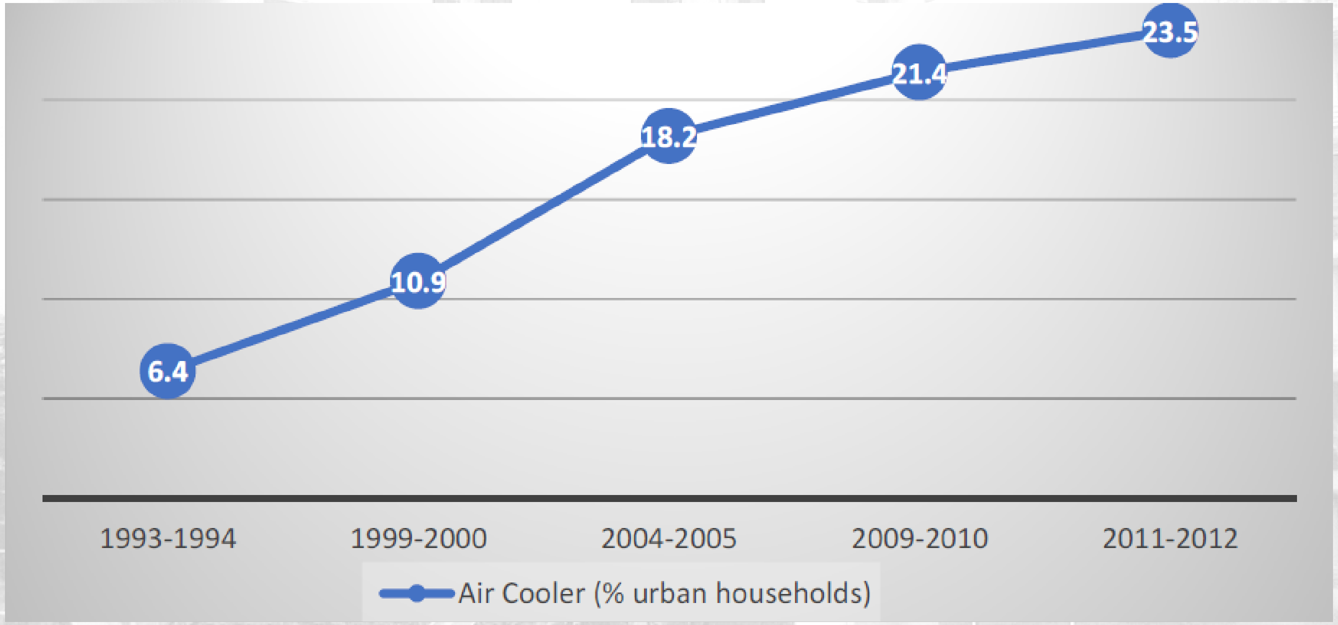
Background: Affordable housing sector in India



- The building sector is the second largest energy consuming sector after the power sector.
- With almost 95% of people falling in middle and lower income brackets, there is a huge demand for affordable mass housing in the coming decades

Source- Confederation of Real Estate Developers' Associations of India (CREDAI). The Economics of Low Income Housing. 2010.

Cooling need in the developing world: the case of urban India



Percentage growth of air cooler (including air conditioner) usage in urban households (Data source: NSSO, India)

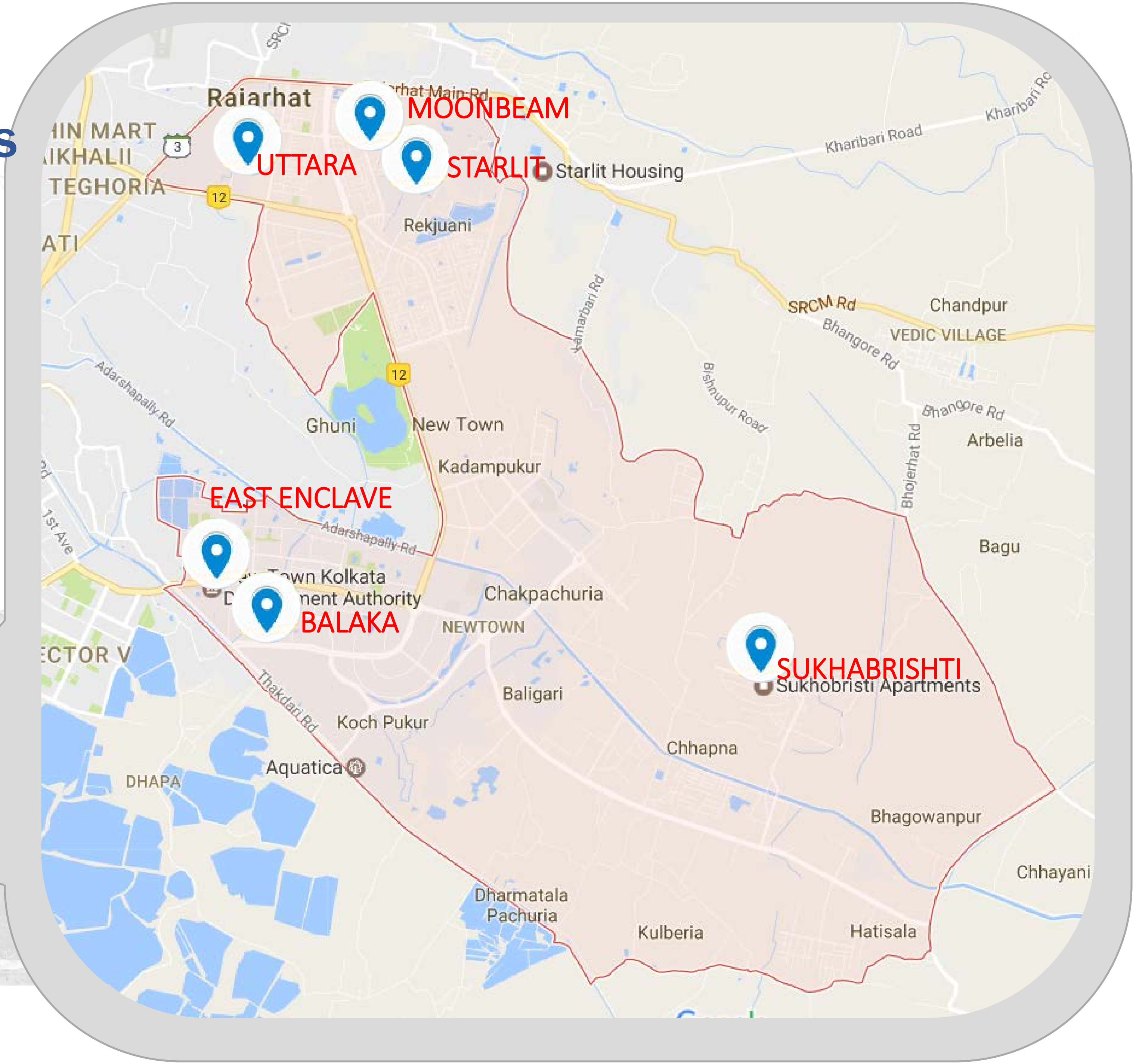
(Source: Sivak, M., 2009. Potential energy demand for cooling in the 50 largest metropolitan areas of the world: Implications for developing countries. Energy Policy 37, 1382–1384)

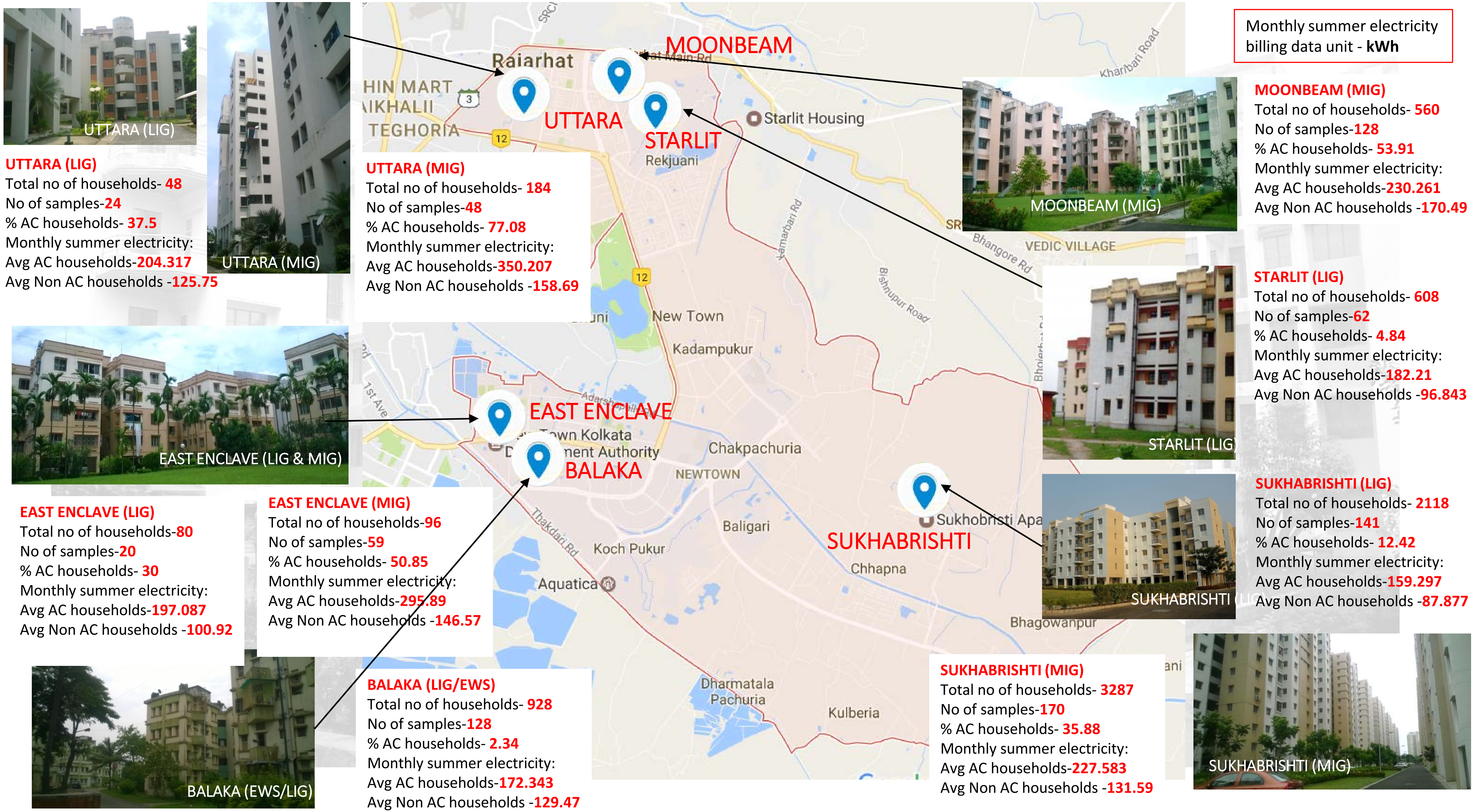
Table 1
Average annual cooling degree days for the 50 largest metropolitan areas in the world.

	Metropolitan area	Country	Population, million (2005)	CDD
1	**Madras**	India	6.9	3954
	Bangkok	Thailand	6.6	3884
	Ho Chi Minh	Vietnam	5.1	3745
4	**Ahmadabad**	India	5.1	3514
	Manila	Philippines	10.7	3438
	Jakarta	Indonesia	13.2	3390
7	**Mumbai**	India	18.2	3386
8	**Hyderabad**	India	6.1	3221
9	**Calcutta**	India	14.3	3211
	Karachi	Pakistan	11.6	3136
11	**Delhi**	India	15.0	2881
	Lagos	Nigeria	10.9	2653
	Dhaka	Bangladesh	12.4	2560
	Miami	USA	5.4	2423
	Rio de Janeiro	Brazil	11.5	2401
16	**Bangalore**	India	6.5	2280
	Baghdad	Iraq	5.9	2142
	Hong Kong	China	7.0	2107
	Shenzhen	China	7.2	2107
	Kinshasa	Congo, DR	6.0	2098
	Guangzhou	China	8.4	2072
	Cairo	Egypt	11.1	1833
	Belo Horizonte	Brazil	5.3	1654
	Lahore	Pakistan	6.3	1309
	Tehran	Iran	7.3	1282
	Wuhan	China	7.1	1277
	Chongqing	China	6.4	1189
	São Paulo	Brazil	18.3	1187
	Osaka	Japan	11.3	1180
	Shanghai	China	14.5	1129
	Tianjin	China	7.0	965
	Tokyo	Japan	35.2	938
	Lima	Peru	7.2	906
	Beijing	China	10.7	840
	Los Angeles	USA	12.3	837
	Madrid	Spain	5.6	805
	Seoul	Korea, South	9.6	746
	Philadelphia	USA	5.4	686
	New York	USA	18.7	639
	Istanbul	Turkey	9.7	567
	Buenos Aires	Argentina	12.6	512
	Chicago	USA	8.8	461
	Santiago	Chile	5.7	290
	Toronto	Canada	5.3	259
	Mexico City	Mexico	19.4	245
	Paris	France	9.8	157
	Moscow	Russia	10.7	138
	London	United Kingdom	8.5	84
	Saint Petersburg	Russia	5.3	73
	Bogotá	Colombia	7.7	0

The entries are in decreasing order of cooling degree days.
The metropolitan areas in developing countries are in **bold**.

Cooling demand from household primary surveys in Rajarhat Township- an eastern metropolitan extension of Kolkata





Monthly summer electricity billing data unit - **kWh**
Rajarhat
MOONBEAM
UTTARA
STARLIT
Rekjuani
Starlit Housing
UTTARA (LIG)
UTTARA (MIG)
UTTARA (LIG)
Total no of households- 48
No of samples-24
% AC households- 37.5
Monthly summer electricity:
Avg AC households-204.317
Avg Non AC households -125.75
UTTARA (MIG)
Total no of households- 184
No of samples-48
% AC households- 77.08
Monthly summer electricity:
Avg AC households-350.207
Avg Non AC households -158.69
MOONBEAM (MIG)
MOONBEAM (MIG)
Total no of households- 560
No of samples-128
% AC households- 53.91
Monthly summer electricity:
Avg AC households-230.261
Avg Non AC households -170.49
VEDIC VILLAGE
New Town
Kadampukur
STARLIT (LIG)
STARLIT (LIG)
Total no of households- 608
No of samples-62
% AC households- 4.84
Monthly summer electricity:
Avg AC households-182.21
Avg Non AC households -96.843
EAST ENCLAVE (LIG & MIG)
EAST ENCLAVE
BALAKA
Chakpachuria
NEWTOWN
SUKHABRISHTI
Baligari
Koch Pukur
Chhapna
Aquatica
SUKHABRISHTI (LIG)
SUKHABRISHTI (LIG)
Total no of households- 2118
No of samples-141
% AC households- 12.42
Monthly summer electricity:
Avg AC households-159.297
Avg Non AC households -87.877
EAST ENCLAVE (LIG)
Total no of households-80
No of samples-20
% AC households- 30
Monthly summer electricity:
Avg AC households-197.087
Avg Non AC households -100.92
EAST ENCLAVE (MIG)
Total no of households-96
No of samples-59
% AC households- 50.85
Monthly summer electricity:
Avg AC households-295.89
Avg Non AC households -146.57
Bhagowanpur
BALAKA (EWS/LIG)
BALAKA (LIG/EWS)
Total no of households- 928
No of samples-128
% AC households- 2.34
Monthly summer electricity:
Avg AC households-172.343
Avg Non AC households -129.47
Dharmatala Pachuria
Kulberia
SUKHABRISHTI (MIG)
Total no of households- 3287
No of samples-170
% AC households- 35.88
Monthly summer electricity:
Avg AC households-227.583
Avg Non AC households -131.59
SUKHABRISHTI (MIG)

Results and deductions

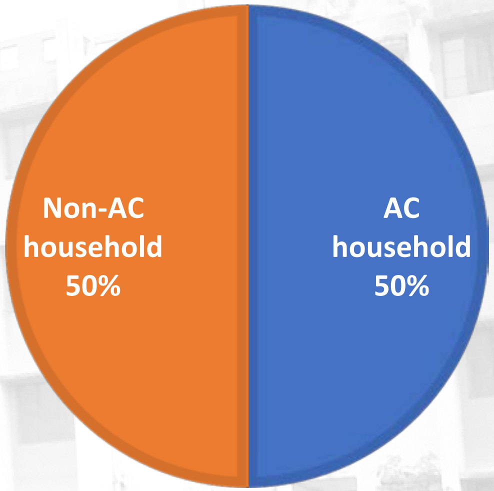
Name of the housing complex in Rajarhat Township	Total no. of households	No. of households surveyed	% households with AC	Mean monthly energy consumption units (kWh) during peak summer in households with AC units	Mean monthly energy consumption units (kWh) during peak summer in households without AC units	Mean % increase in monthly energy consumption in household with AC units
MIG						
Sukhabrishti	3287	170	36	227.58	131.59	72.94
Moonbeam	560	128	54	230.26	170.49	35.06
East Enclave	96	59	51	295.89	146.57	101.87
Uttara	184	48	77	350.21	158.69	120.69
LIG						
Sukhabrishti	2118	161	12	159.30	87.877	81.27
Starlit	608	62	4	182.21	96.843	88.15
Balaka	928	128	2	172.34	129.47	33.11
East Enclave	80	20	30	197.09	100.92	95.28
Uttara	48	24	37	204.32	125.75	62.47

Dataset for AC electricity consumption in LIG and MIG households from household primary surveys

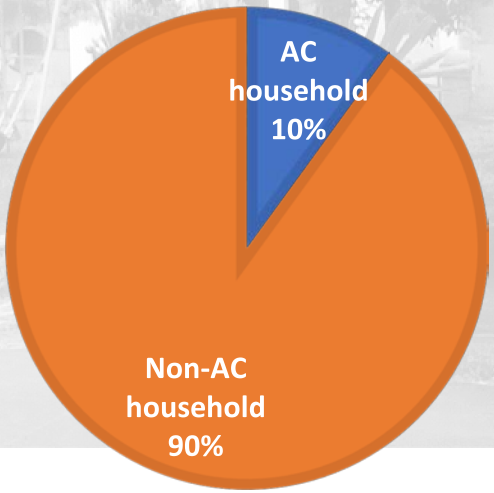
Results and deductions

- 35-77% middle income group (MIG) housing units and 5-37% low income group (LIG) housing units were found to have air conditioning units. On average about **50% MIG** houses and **10% LIG** houses had ACs
- % increase is electricity billing varies between 35-120% for MIG and 33-95% in LIG, the average total increase being **80% excess electricity consumption**
- Implied current low AC saturation and **future growth in cooling demand**
- Implied **high operating cost** of individual room air conditioners

SURVEYED MIG HOUSING

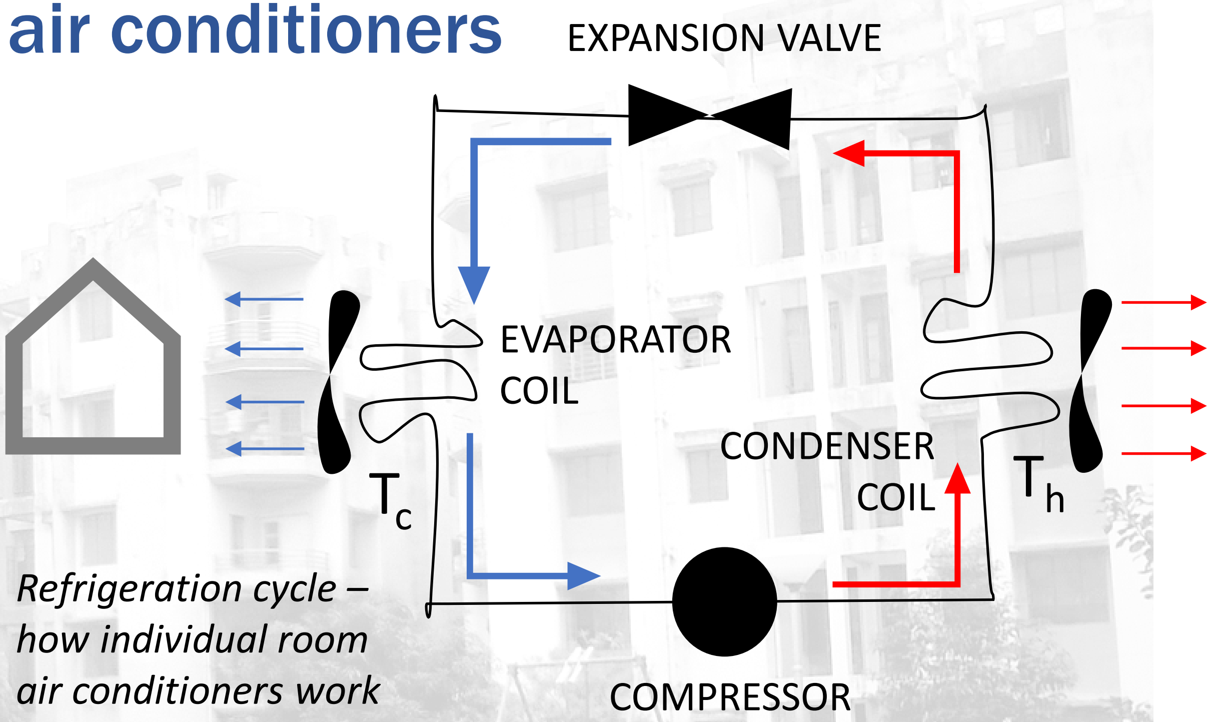


SURVEYED LIG HOUSING



Existing scenario – individual room air conditioners

Individual room air conditioner at Sukhabrishti mass housing complex



Refrigeration cycle – how individual room air conditioners work

$g = 0.5$

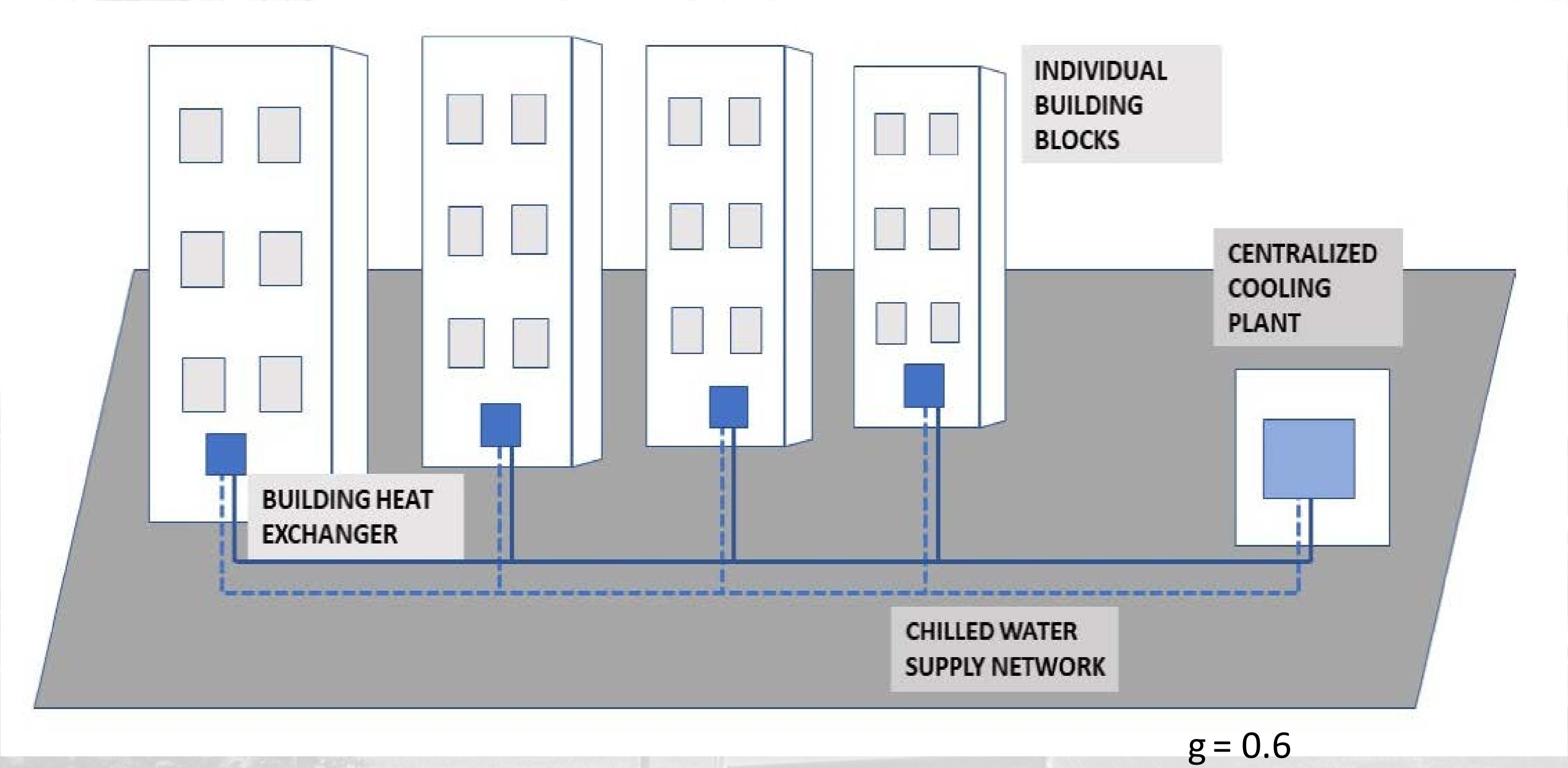
$T_h = 55\text{-}60°C$

$T_c = 8°C$

COP ~ 2.7-2.9

- **Easily available**, consumer market driven
- **High operating costs** and AC electricity consumption – hence **low efficiency**
- Rejected heat from AC condensers giving rise to the ‘**stack effect**’ – reduction of AC efficiency in upper floor

Community scale cooling scenario – district cooling system



Schematic view of a district cooling network (source: authors)

g = 0.6

T_h = 30-35°C

T_c = 8°C

COP ~6.2-7.6

- **Chilled water is distributed** from a centralized chiller plant to the housing complexes
- Consists of a central **chiller** plant, chilled water **supply network** and **building heat exchanger**
- **Centralized heat rejection** (assumed temperature at evaporative cooling tower T_h = 30-35°C)
- Higher exergetic efficiency

Key benefits of centralized cooling

ENERGY EFFICIENCY BENEFITS

- Higher COP and hence **lower cooling energy consumption**

CLEAN ENERGY AND EMISSION REDUCTION BENEFITS

- **Easy integrability with renewable** energy sources in centralized chiller plant
- **Prevents GHG emissions** from **air conditioning refrigerants**

FINANCIAL BENEFITS

- **Lower operating costs** in the long run
- **Shift of capital cost** of buying split units from individual to community level

QUALITATIVE BENEFITS

- Centralized O&M makes it a **more reliable service**
- **Improves urban microclimate** by centralized heat rejection
- **Improves urban aesthetics** as individual units disrupt view of facades

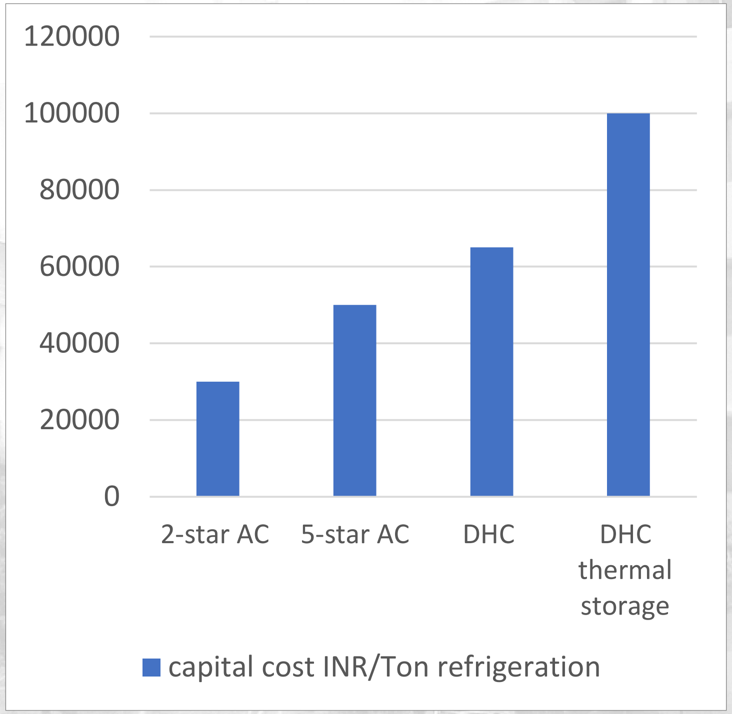
Institutional mechanisms for implementing district cooling

Private Developer	Energy Servicing Companies (ESCO)
Governmental support	International Actors

Private Developer as enabler of district cooling infrastructure

Private developer as project financer for mass housing - usually in a PPP model

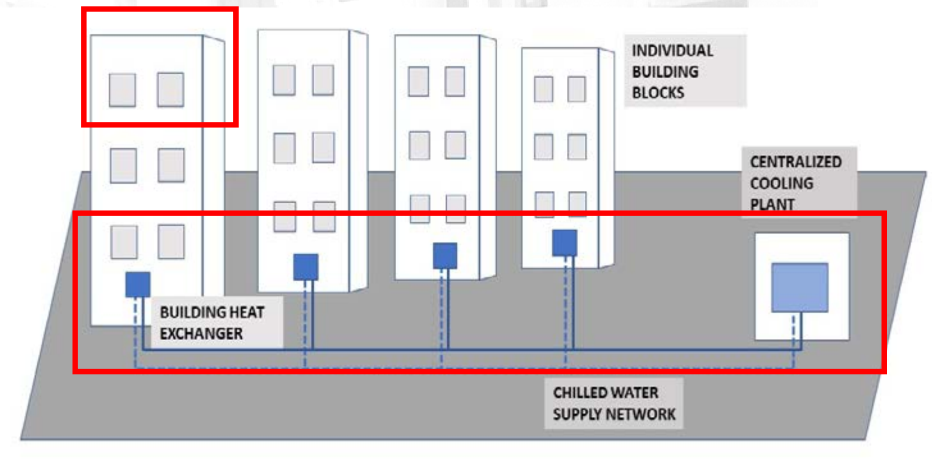
- Potential actor for capturing cost effective energy efficient technologies in mass housing communities



1ton DHC would be around 60000-70000 INR without thermal storage and around 100000 INR with thermal storage against 50000 INR for 5 star rated and 30000 INR for 2 star rated 1.5 ton AC

Private Developer as enabler of district cooling infrastructure

A Build-Own-Operate (BOO) model for implementing district cooling as community level infrastructure by private developer



- Market survey revealed district cooling has **40-70% more upfront investment costs** as compared to individual units, however the **investment is shifted from individual to community level**

- District cooling constitutes only **4-8% construction cost** of an entire apartment complex- and could act as a subsequent source of revenue generation during the operating phase of the housing complex

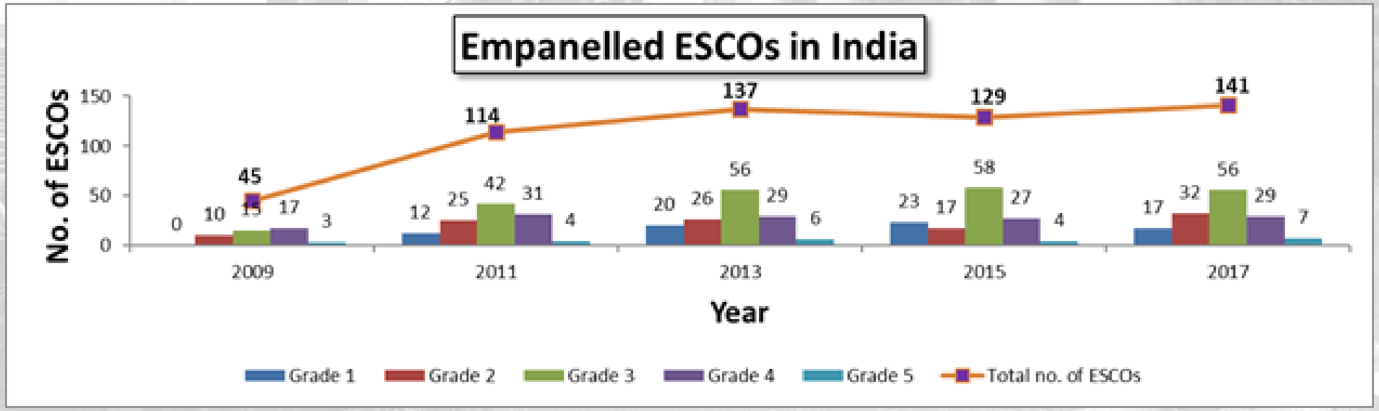
1500 INR/sq ft, 750-1500sqft >> 1125K-2250K INR capital cost with 60-100K INR AC construction cost

4-8% of construction cost

Role of other enabling actors

- **ESCOs – enablers** of energy infrastructures, services offered are as follows

Project Identification → Financing/ arrangement for financing → Installation of Technology/ Equipment → Operation and Maintenance → Monitoring and Measurements of project energy savings



Source: Bureau of Energy Efficiency, India

Offering energy services –design, retrofitting and implementation- after identifying energy saving opportunities

Role of other enabling actors

- **Governmental support –**

Incentives	Subsidies	Tax Exemptions

- **International actors -**

Project Financing	Increasing awareness among stakeholders

SUMMARY OF CONCLUSIONS

- **Rapid increase in household air cooler ownership** in India every year from National Sample Survey Organization -reported increase in 2% households from 2009-2010 to 2010-2011
- As observed from household primary surveys, 35-77% MIG housing units and 5-37% LIG housing units were found to have air conditioning units.- on average about **50% MIG houses and 10% LIG houses had ACs**
- percentage increase is electricity billing varies between 35-120% for MIG and 33-95% in LIG, the **average total increase being 80%**
- District cooling systems could decrease the summer monthly AC electricity consumption by **60-65%**
- Easy integrability with renewable energy sources, avoiding GHG emitting air conditioning refrigerants, lowering operating costs in long run, improving urban microclimate and urban aesthetics and overall QoL
- District cooling constitutes only **4-8% construction cost** of an entire apartment complex- and could act as a subsequent source of revenue generation during the occupancy phase of the housing complex for the **private developer** to invest in such community scale cooling infrastructures
- However district cooling technology comes with **challenges** of **high upfront investment costs** and the need for **high amount of cooling load** to be the feasible model for a ‘smart community’

Future work..

Quantifying the housing **density scale** in which district cooling can be profitable in residential neighbourhoods and identifying break-even point for profitability

Site plan – Sukhabrishti mass housing complex

CASE STUDY HOUSING
Sukhabrishti Mass Housing Complex
Middle Income Housing (MIG)
Total MIG – 3287
35% households having ACs
Summer monthly average cooling demand each household- 298196-320285kWh (assuming COP range 2.7-2.9)

Special thanks to Prof. ***Forrest Meggers***, my mentor and collaborator at the CHAOS lab at the Andlinger Center for Energy and Environment at ***Princeton University*** for introducing me in this area of low exergy community cooling during my ***Fulbright exchange program*** as a doctoral student from IIT Kharagpur India in 2017


THANK YOU!