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ASIA LOW CARBON BUILDINGS TRANSITION PROJECT
Life Cycle Assessment for Transitioning to a Low-Carbon Economy

2.5 Operational Energy – Opportunities for Optimization

November 2024

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

INTERNATIONAL CLIMATE INITIATIVE

WHAT WILL YOU LEARN?

01 Approach for Operational Energy Reduction

02 Operational Energy Reduction in HVAC

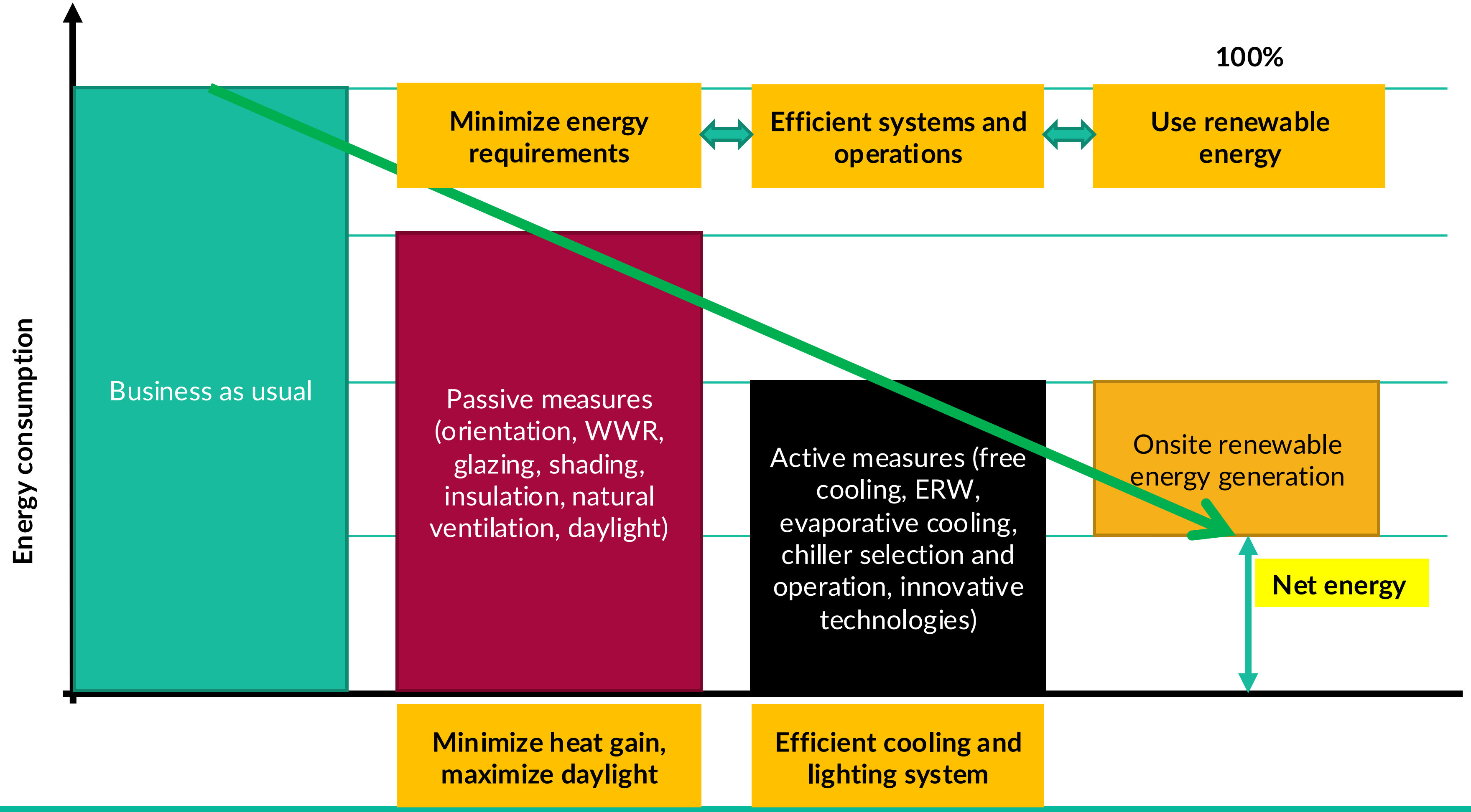
03 Operational Energy Reduction in Lighting

04 Operational Energy Reduction in Other Services

05 Integration of Renewable Energy

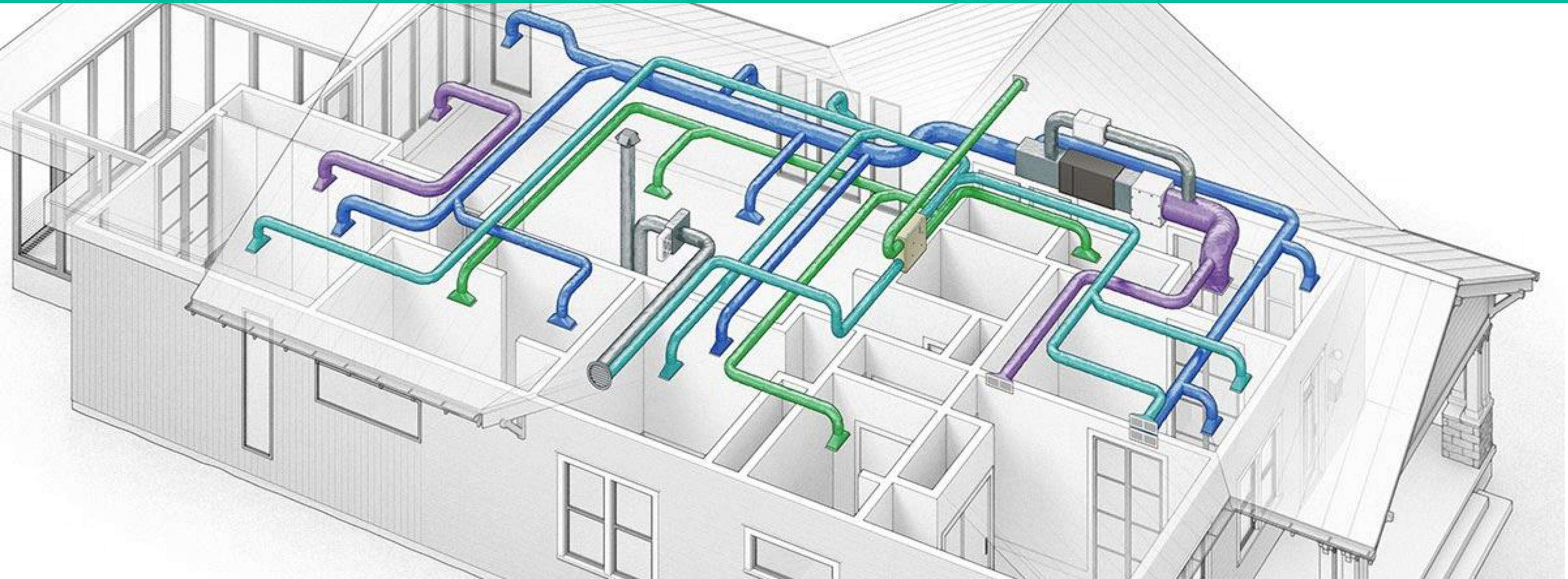
OPERATIONAL ENERGY REDUCTION

First step: Minimize energy requirement by adopting passive measures



- First, reduce energy requirement of the building using passive measures
- Integrated design process is imperative to achieve operational energy goals

Operational Energy Reduction in HVAC



SIZING THE HVAC SYSTEM

Factors for optimization

Depends on several factors:

- Ambient conditions (temperature, humidity, solar radiation, wind)
- Internal conditions (stringent setpoints, adaptive comfort)
- Building usage and internal loads (occupants, lighting loads, equipment loads)
- Building envelope (wall, window, roof) and its properties (passive measures that helps in load or required size reduction)

Do not consider only the worst possible scenario
Use calculation sheets and software tools to size the system optimally

Target kW/TR of cooling?

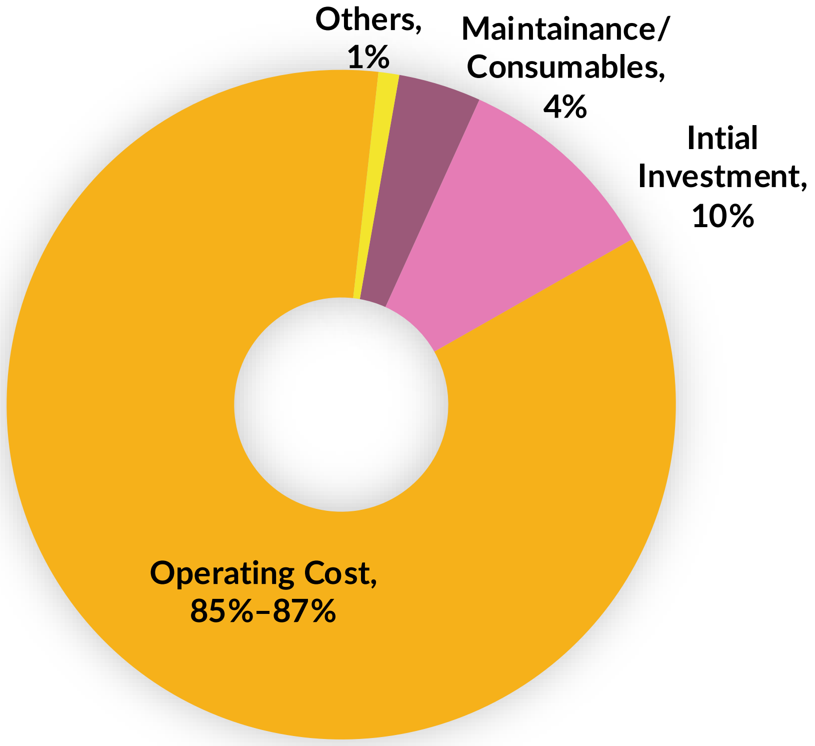
HVAC: LIFE CYCLE COSTING

Energy cost is the obvious focus area

Consider operational life of 15 years for equipment and systems

- The initial capex is about 10%
- Cost of operation and maintenance is 3%–5%
- **Operating cost (energy consumed) is 85%–87%**

Select systems and equipment with long-term perspective and not just initial cost

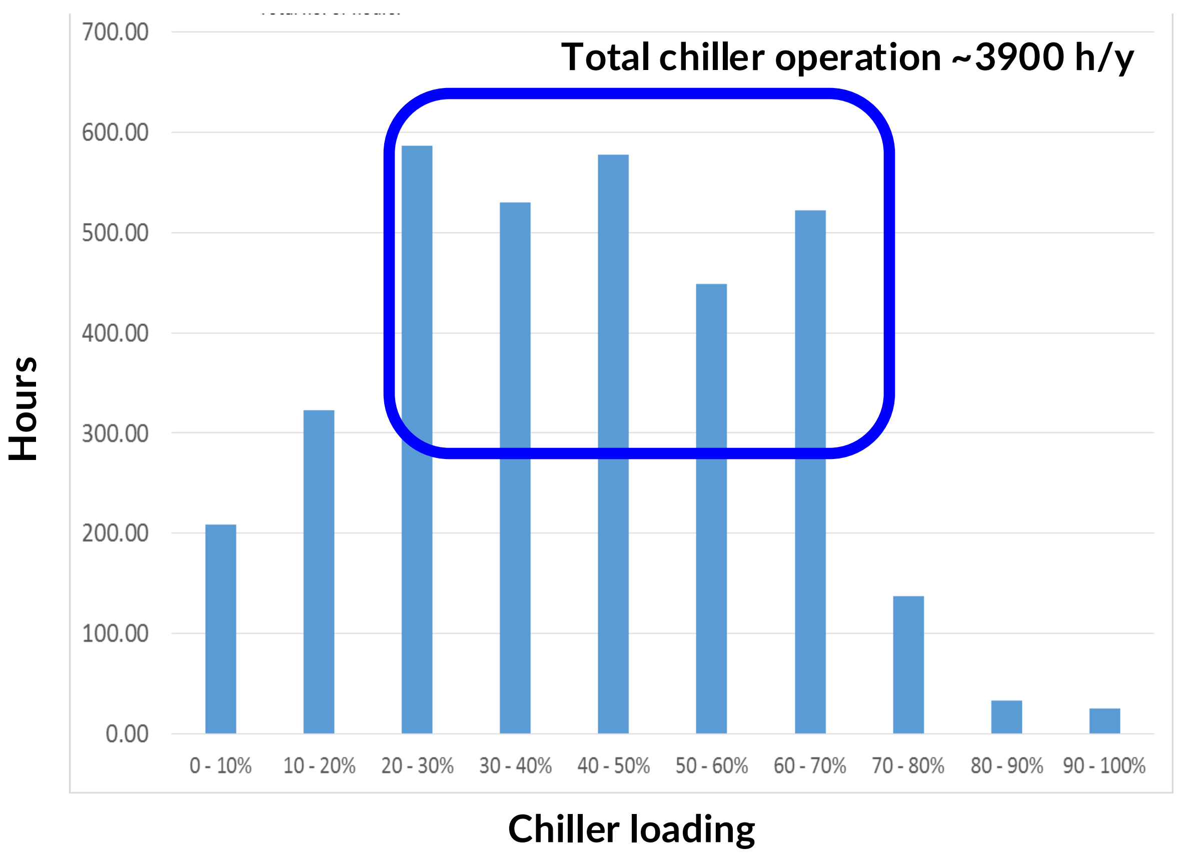


SELECT EFFICIENT SYSTEMS

Part-load performance is important

- Most equipment have a full-load minimum efficiency metric that is based on standard conditions at rated full-load
- When selecting system, it is important to check the part-load performance, which gives system efficiency at varying loads and operating conditions
- Some figures of merit for chillers are:
  - Integrated part-load value (IPLV)
  - Integrated energy efficiency ratio (IEER)
  - Seasonal energy efficiency ratio (SEER)
- Loads may vary significantly with climatic conditions and building utilization

Select a system that gives better part-load performance in the most frequently operating load band



Example: Load variations on a chiller

SYSTEM EFFICIENCY

Guidance on minimum efficiency levels

- The system efficiency levels are prescribed at both international and national levels, and are updated at regular intervals
- Internationally, the minimum equipment efficiency values defined in **ASHRAE Standard 90.1** are well recognized and widely used. Meeting the prescriptions of the latest edition can ensure that selected systems will require lower operational energy
- At national levels, the local codes or standards will **supersede**; for example, in **India**, the **Energy Conservation Building Code (ECBC)** is applicable to both commercial and residential buildings. The minimum equipment efficiency values are prescribed with reference to local conditions, available systems and future prescriptions on minimum performance levels

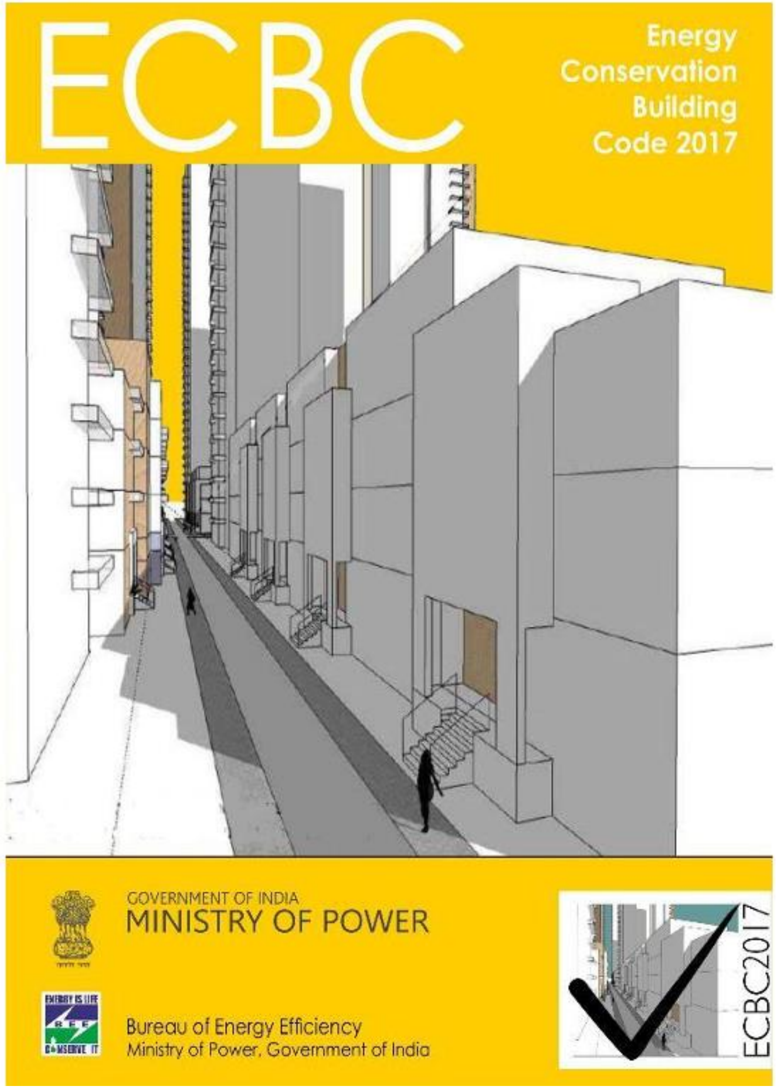


Image source: Bureau of Energy Efficiency, Government of India, 2017

UNITARY AIR CONDITIONERS

ECBC 2017 (India) prescriptions for COP of unitary air conditioners

Requirements for unitary, split, packaged air conditioners

Cooling Capacity		ECBC Buildings		ECBC+ Buildings		Super ECBC Buildings	
kW_r	TR	Water-cooled	Air-cooled	Water-cooled	Air-cooled	Water-cooled	Air-cooled
≤ 10.5	≤ 3	NA	BEE 3 Star	NA	BEE 4 Star	NA	BEE 4 Star
> 10.5	> 3	3.3 EER	2.8 EER	3.9 EER	3.4 EER	3.9 EER	3.4 EER

- The criteria given under 'ECBC Buildings' are mandatory in India as per ECBC 2017
- The criteria for 'ECBC+ Buildings' and 'Super ECBC Buildings' are optional; however, they give specifications for more efficient systems

Source: Bureau of Energy Efficiency, Government of India, 2017

AIR COOLED VRF AIR CONDITIONERS

ECBC 2017 (India) prescriptions for COP of VRF air conditioners

Mandatory requirements for air-cooled variable refrigerant flow (VRF) air conditioners under ECBC Buildings

		For Heating or cooling or both	
Type	*Size category (kWr)*	*EER (W/W)*	*IEER (W/W)*
VRF Air Conditioners, Air cooled	< 40	3.28	4.36
	>= 40 and < 70	3.26	4.34
	>= 70	3.02	4.07

Source: Bureau of Energy Efficiency, Government of India, 2017

CHILLER EFFICIENCIES

ECBC 2017 (India) prescriptions for COP of chillers

Mandatory requirements for chillers

Chiller	ECBC Buildings	ECBC+ Buildings	Super ECBC Buildings
All	BEE 1 star	BEE 3 star	BEE 5 star

Star rating levels for water-cooled chillers
(valid from January 1, 2024 to December 31, 2025)

kW of Cooling	ISEER				
	1 Star	2 Star	3 Star	4 Star	5 Star
<260	4.80	5.20	5.60	6.10	6.60
>=260 and <530	5.00	5.60	6.20	6.80	7.40
>=530 and <1,050	5.50	6.10	6.70	7.40	8.20
>=1,050 and <1,580	5.80	6.50	7.20	7.90	8.70
>=1,580	6.00	6.70	7.40	8.20	9.00

Star rating levels for air-cooled chillers
(valid from January 1, 2024 to December 31, 2025)

kW of Cooling	ISEER				
	1 Star	2 Star	3 Star	4 Star	5 Star
<260	3.00	3.30	3.60	4.00	4.40
>=260	3.10	3.50	3.90	4.30	4.70

Source: Bureau of Energy Efficiency, Government of India, 2017

COOLING TOWER

ECBC 2017 (India) prescriptions for cooling towers

Prescribed cooling tower pumping power for ECBC, ECBC+ and Super ECBC Buildings

Equipment type	*Rating Condition*	*Efficiency*
Open circuit cooling tower Fans	35°C entering water 29°C leaving water 24°C WB outdoor air	0.017 kW/kW$_r$ *0.31 kW/ L/s*

ECBC+ and Super ECBC Buildings have additional requirements for VFD installed in cooling tower fans

Source: Bureau of Energy Efficiency, Government of India, 2017

PUMPS IN HVAC SYSTEMS

ECBC 2017 (India) prescriptions for power of pumps

Prescribed installed pumping power

Equipment	ECBC Buildings	ECBC+ Buildings	Super ECBC Buildings
Chilled Water Pumps (Primary and Secondary)	18.2 W/kW_r with VFD on secondary pump	16.9 W/kW_r with VFD on secondary pump	14.9 W/kW_r with VFD on secondary pump
Condenser Water Pumps	17.7 W/kW_r	16.5 W/kW_r	14.6 W/kW_r
Pump Efficiency	Min. 70%	Min. 75%	Min. 85%

Source: Bureau of Energy Efficiency, Government of India, 2017

UTILITY PLANT ROOM

ECBC 2017 (India) prescriptions for central chilled water plant

In ECBC 2017, the efficiency of the entire plant room has been specified for all categories of the buildings

System Type	Peak Building Cooling Load (kW)	
	< 3,516 kW	≥ 3,516 kW
Central Chilled Water Plant (Water Cooled)	0.21 (kW/kW_r) 0.74 (kW/TR)	0.20 (kW/kW_r) 0.70 (kW/TR)
Minimum system efficiency based on total installed equipment power per unit cooling capacity		

Reference System Efficiency	ECBC	ECBC+	Super ECBC
HVAC Plant Room, kW/kW_r	0.26	0.23	0.20

Source: Bureau of Energy Efficiency, Government of India, 2017

AHU FAN EFFICIENCIES

ECBC 2017 (India) prescriptions on minimum AHU fan efficiencies

Prescribed minimum mechanical efficiency and motor efficiency for fans in ECBC Buildings

System type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	60%	IE 2

Prescribed minimum mechanical efficiency and motor efficiency for fans in ECBC+ Buildings

System type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	65%	IE 3

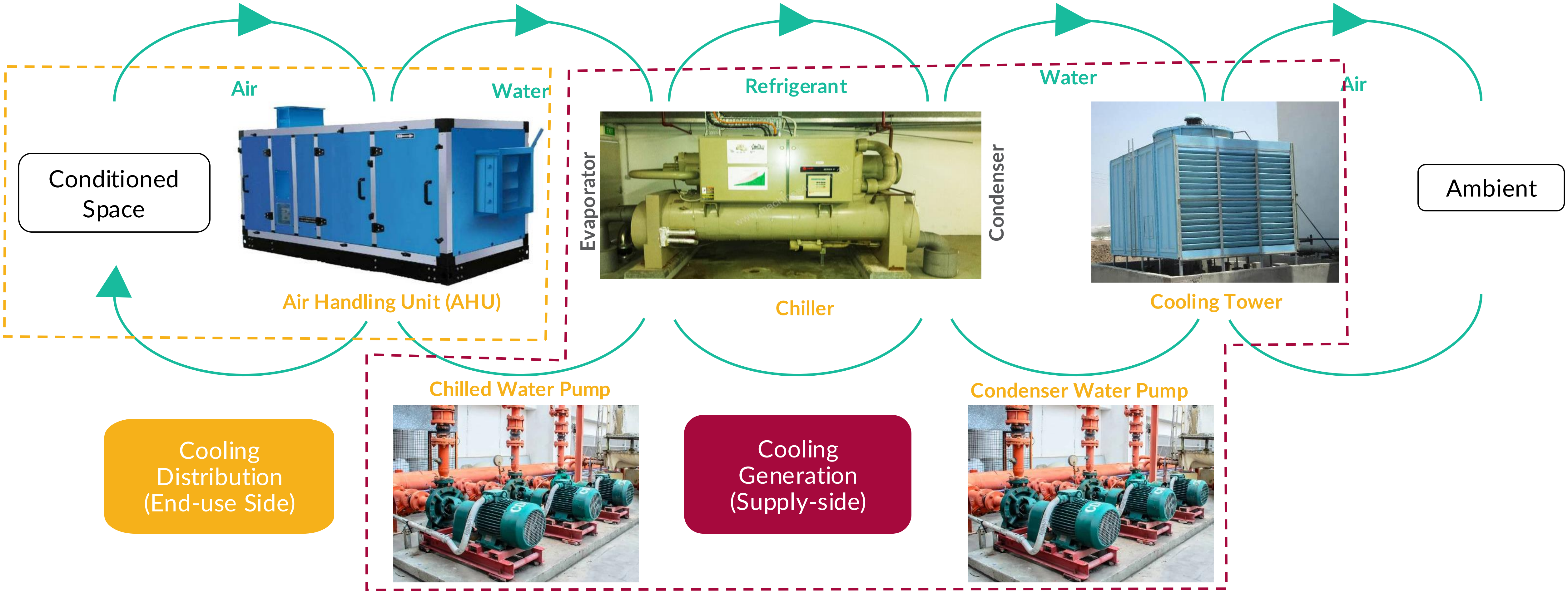
Prescribed minimum mechanical efficiency and motor efficiency for fans in Super ECBC (ECBC+) Buildings

System Type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	70%	IE 4

Source: Bureau of Energy Efficiency, Government of India, 2017

TYPICAL COOLING SYSTEM (CENTRALIZED)

Two key segments



OPTIMIZING CENTRALIZED SYSTEM

Key strategies

Cooling Generation

- Increase the chilled water generation temperature
- Decrease the condenser water temperature
- Use VFD for chillers
- Pump selection

Cooling Distribution

- Minimize the air distribution path
- Enthalpy recovery
- Free cooling
- Use VFDs

Use building management systems (BMS) and building automation systems (BAS) to optimize operations

CHILLED WATER TEMPERATURE

Design option for operation at higher chilled water temperature

Design for higher chilled water temperature: Radiant cooling system

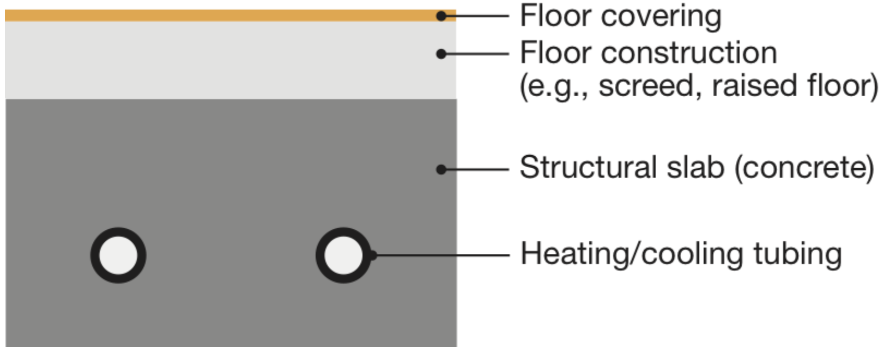
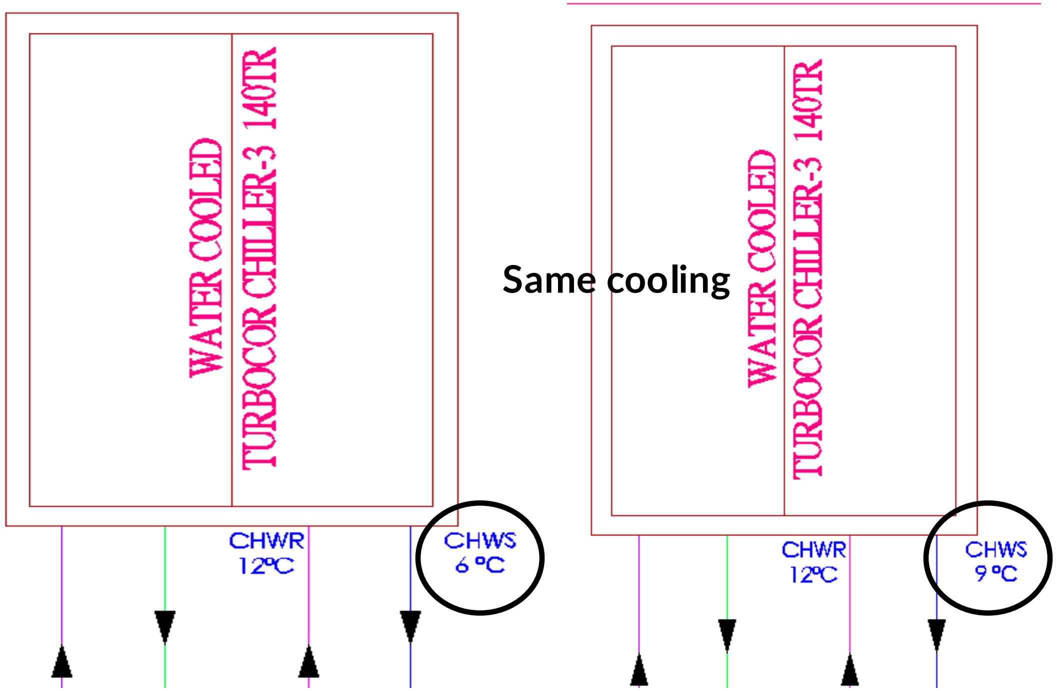


Image source: Infosys. India

Operate at higher chilled water temperature



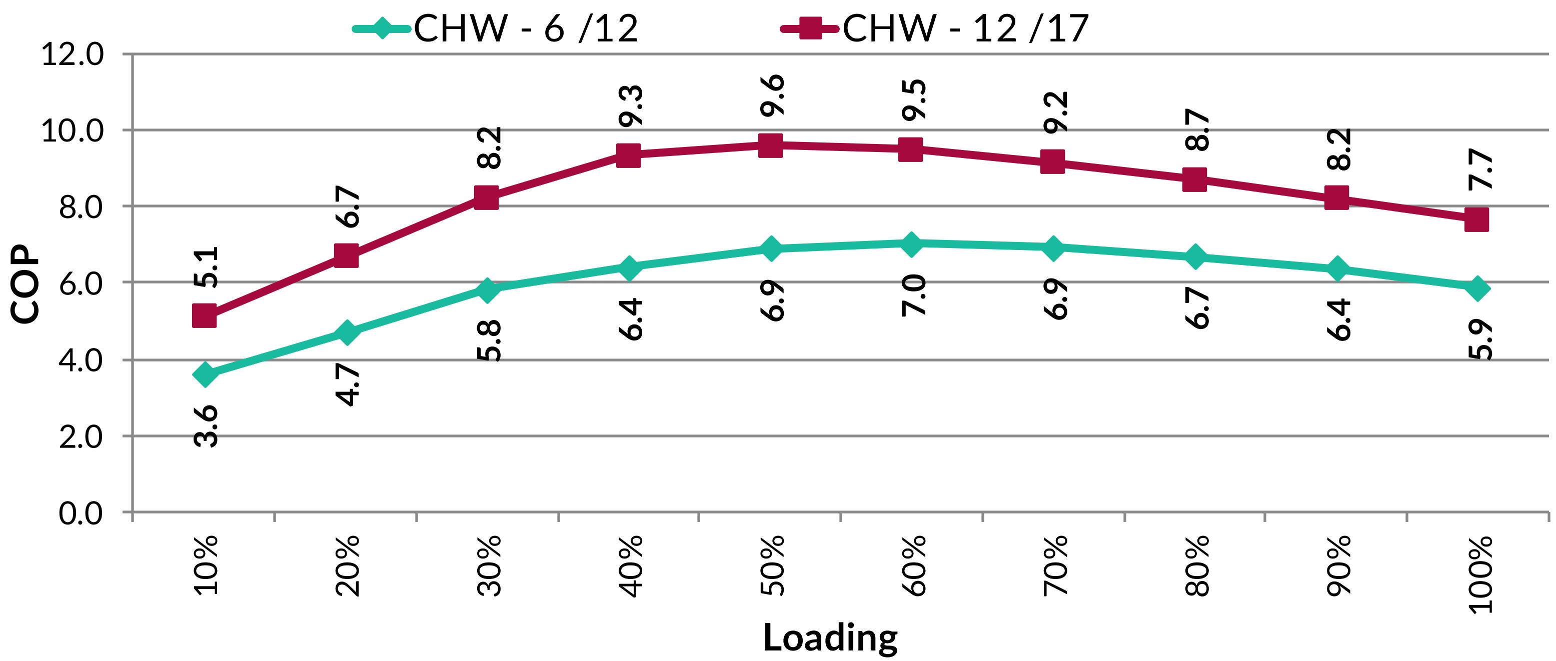
Flow: X

Flow: 2X

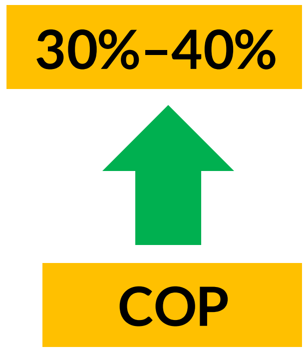
Limiting factor: Temperature required for **dehumidification**

CHILLED WATER TEMPERATURE

Impact of operation at higher chilled water temperature



Less power input for compressor; leading to increase in COP



Note: At constant condenser cooling water inlet / outlet temperatures of 28°C / 34°C

Source: Ministry of Power, Government of India, 2022a

COOLING WATER TEMPERATURE

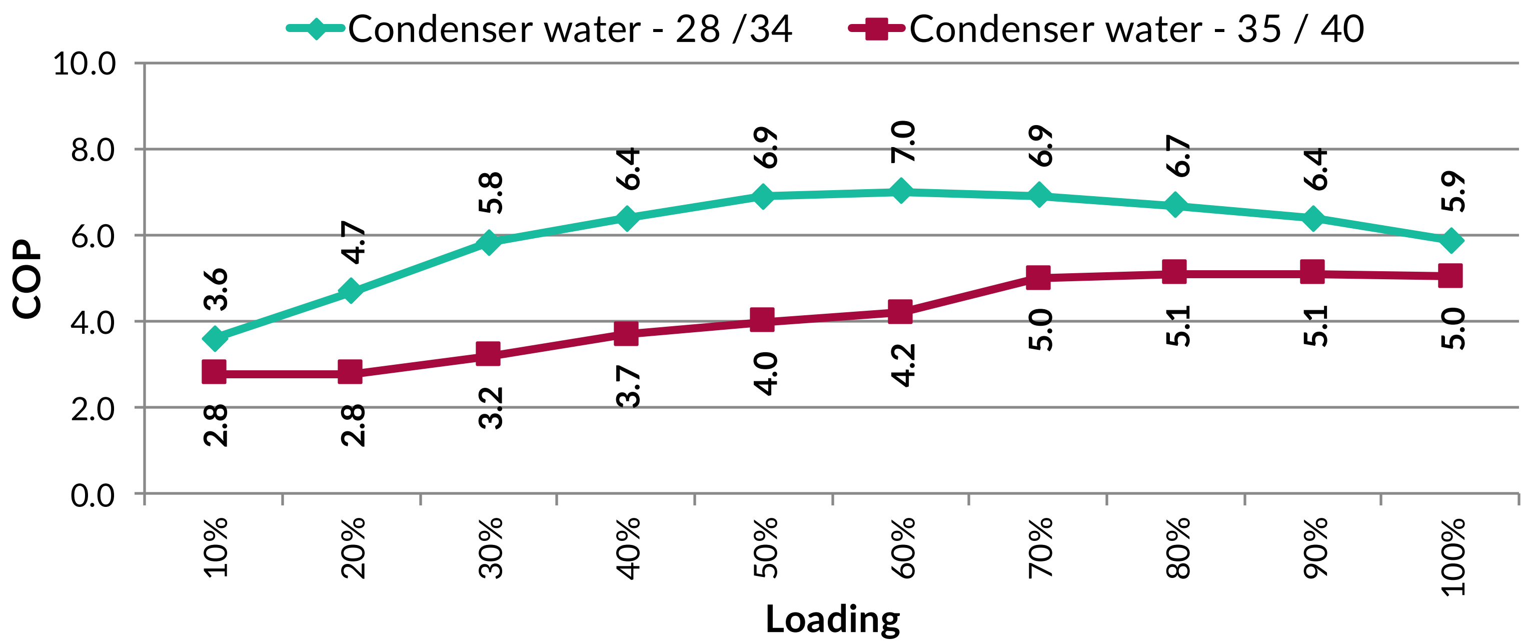
Options for lower condensing temperature

- Use water cooling or evaporative cooling of condensers instead of air-cooled condensers. This is desirable for reducing chiller power consumption
- Use cooling tower with low approach temperature (1°C–2°C) to improve heat transfer effectiveness in the condenser. This lowers the condensing temperature, thus, reduces the power input for the compressor and increases COP
- The limiting factor is water availability. Due to water scarcity, many urban local bodies in India do not permit the use of freshwater for HVAC cooling applications

Parameters	Unit	Water-cooled Chiller	Air-cooled Chiller	Evaporative Chiller
Refrigerant		R-134 a	R-134 a	R-134 a
Capacity	TR	100	100	100
Water Flow across Condenser	m^3/hr	60.5	NA	30.3
Condenser Pump Power	kW	5.51	NA	1.52
Condenser / CT Fan Power	kW	NA	15.12	NA
Compressor Power Consumption	kW	77.56	110.22	66.44
Specific Power Consumption	**kW/TR**	**0.78**	**1.10**	**0.66**
Evaporator Refrigerant Temp.	°C	2.0	2.0	2.0
Evaporator Refrigerant Pressure	bar	3.1	3.1	3.1
Condenser Refrigerant Pressure	bar	8.5	11.3	7.6
Condenser Refrigerant Temp.	°C	33.5	44.0	29.5
Make Up Water Requirement	m^3/hr	0.58	NA	0.52

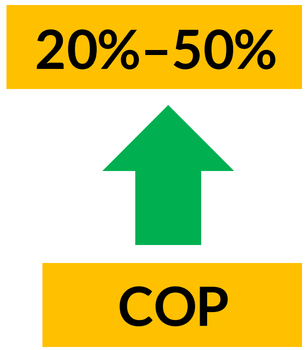
DECREASING CONDENSER WATER TEMPERATURE

What's the impact?



Note: At constant chilled water inlet / outlet temperatures of 12°C / 6°C

Less power input for compressor; leading to increase in COP

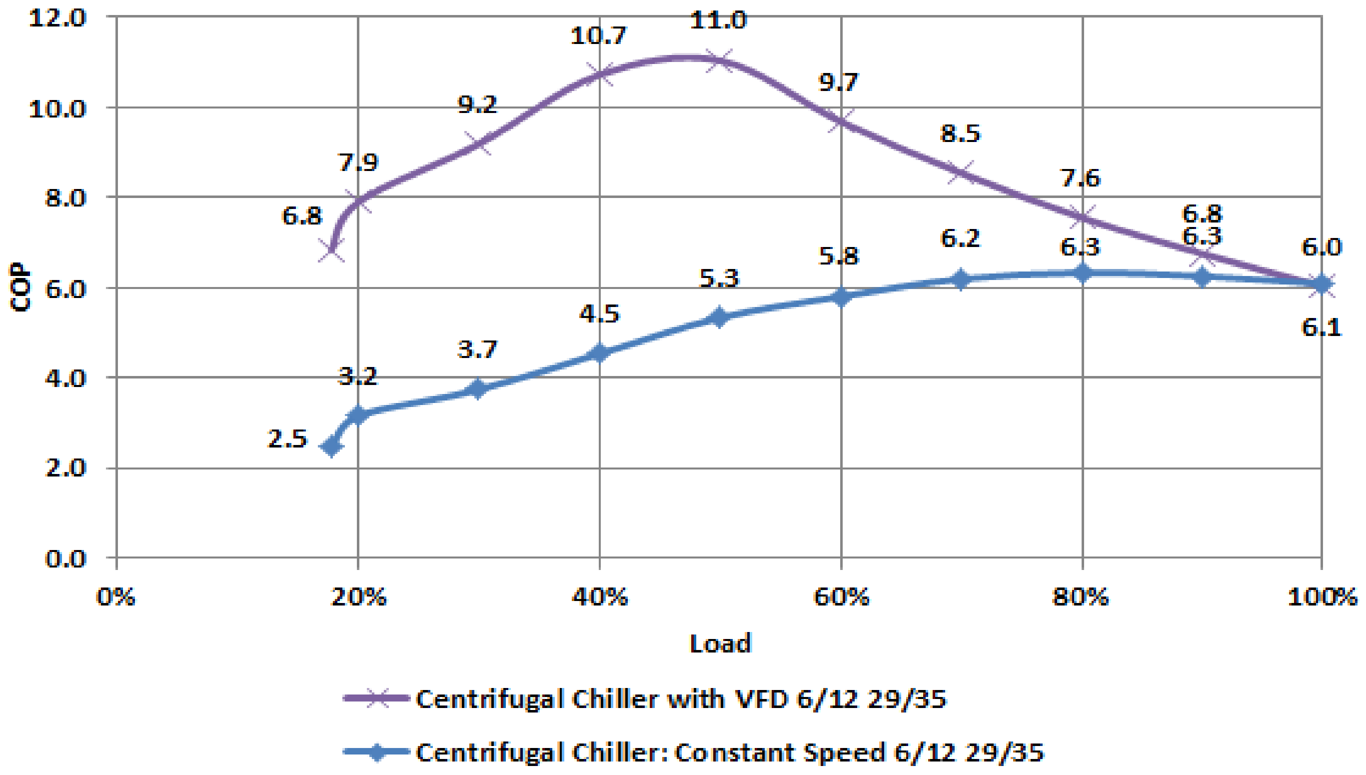


Source: Ministry of Power, Government of India, 2022a

VFD FOR CHILLERS

Energy efficient capacity control at partial loads

- Variable frequency drive (VFD) varies the electrical frequency to electric motor speed, eliminating the need for relatively inefficient methods of capacity control like cylinder unloading for reciprocating compressors, sliding valve control for screw compressors and inlet guide vane control for centrifugal compressors
- Elimination of energy losses from these inefficient capacity control devices, coupled with significant improvements in heat transfer effectiveness in evaporator and condenser, the chiller COP increases dramatically
- As the chillers operate on part-load most of the time, the energy consumption reduces significantly

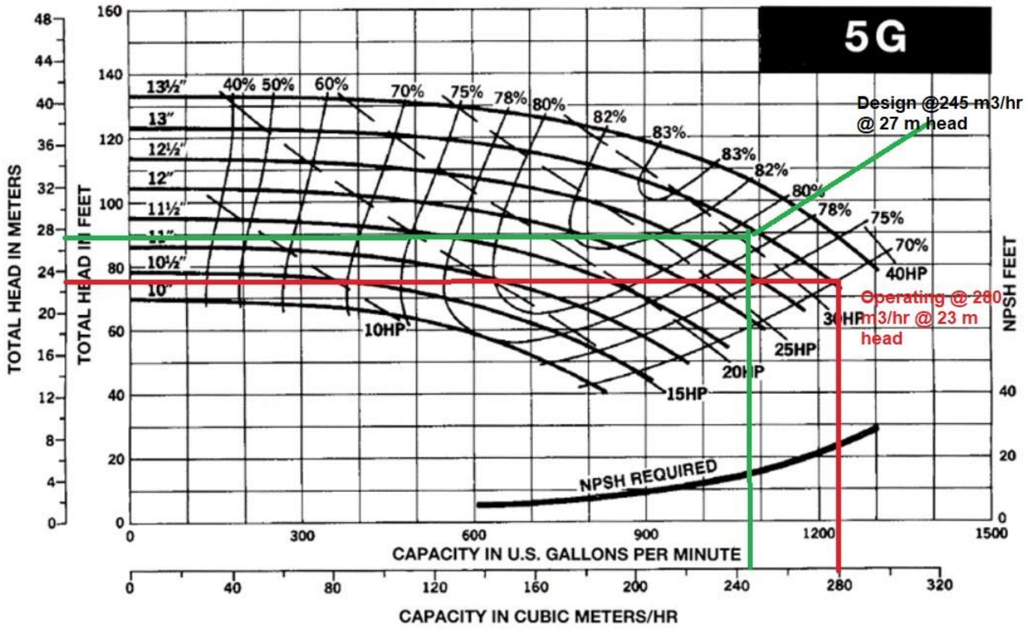


Source: Ministry of Power, Government of India, 2022a

PUMPS SELECTION

Selection of appropriately sized, efficient pumps

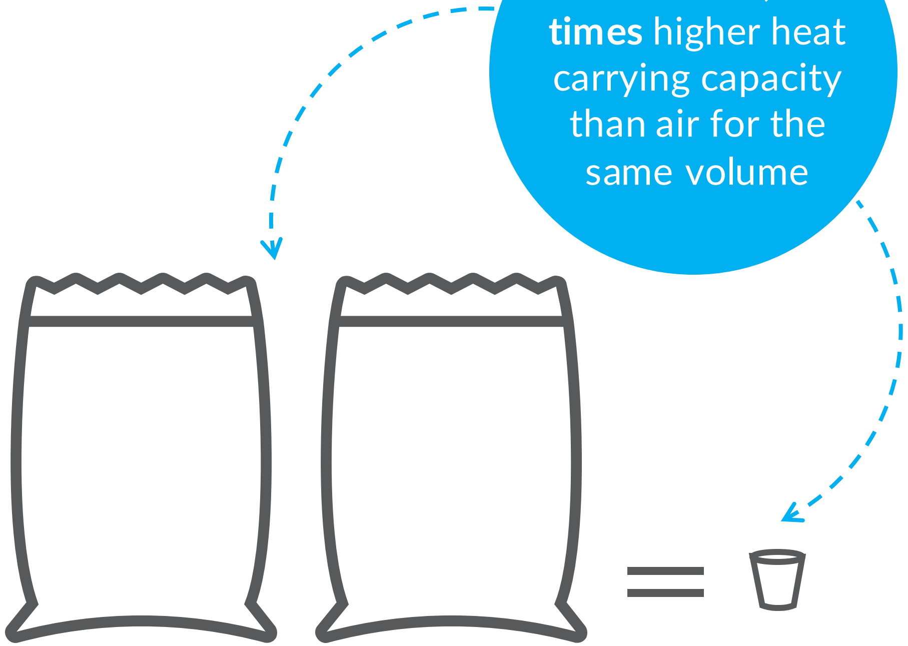
- In the HVAC system, flow through condenser and evaporator is important, and minimum flow must be maintained for smooth functioning of chillers
- The pressure drop across condenser and evaporator, associated friction drop on piping, and static lift determine the operating energy consumed by the pumps. These parameters should be calculated accurately before selection of pumps
- The head and flow for the pumps must be selected with minimum margins and maximum available pump efficiency to ensure efficient operation
- In case the selected head is more than the operating head, then the pump would tend to deliver more flow than the design value and would consume more power and operate at lower efficiency



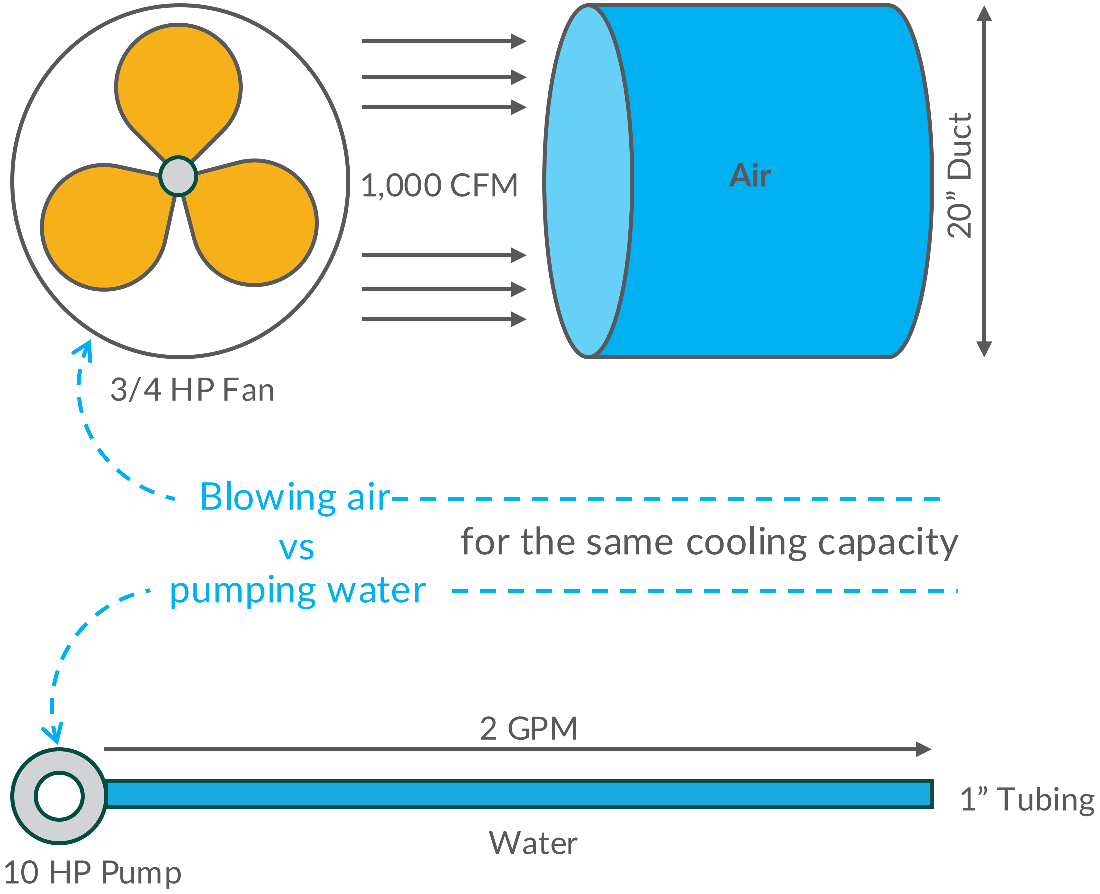
RADIANT COOLING

Leveraging the heat carrying capacity of water

Water has **3,400 times** higher heat carrying capacity than air for the same volume



The heat capacity of one cup of water is equal to the heat capacity of two bags of air

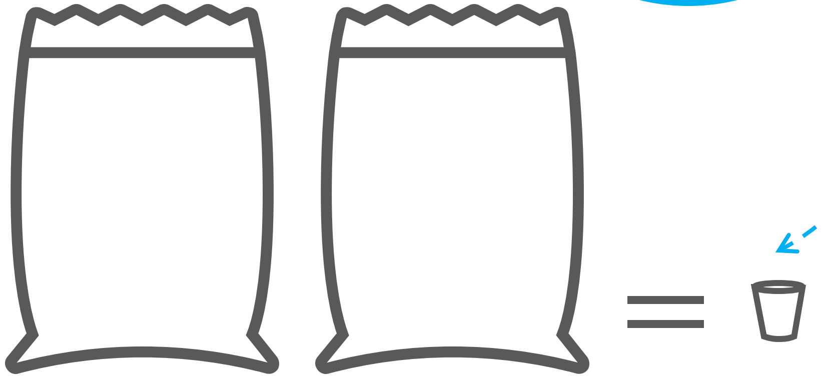


MINIMIZE COOL AIR DUCTING

Chilled water is comparatively a better heat transfer medium than air

Use water to transport heat until the farthest end possible

Water has **3,400 times** higher heat carrying capacity than air for the same volume



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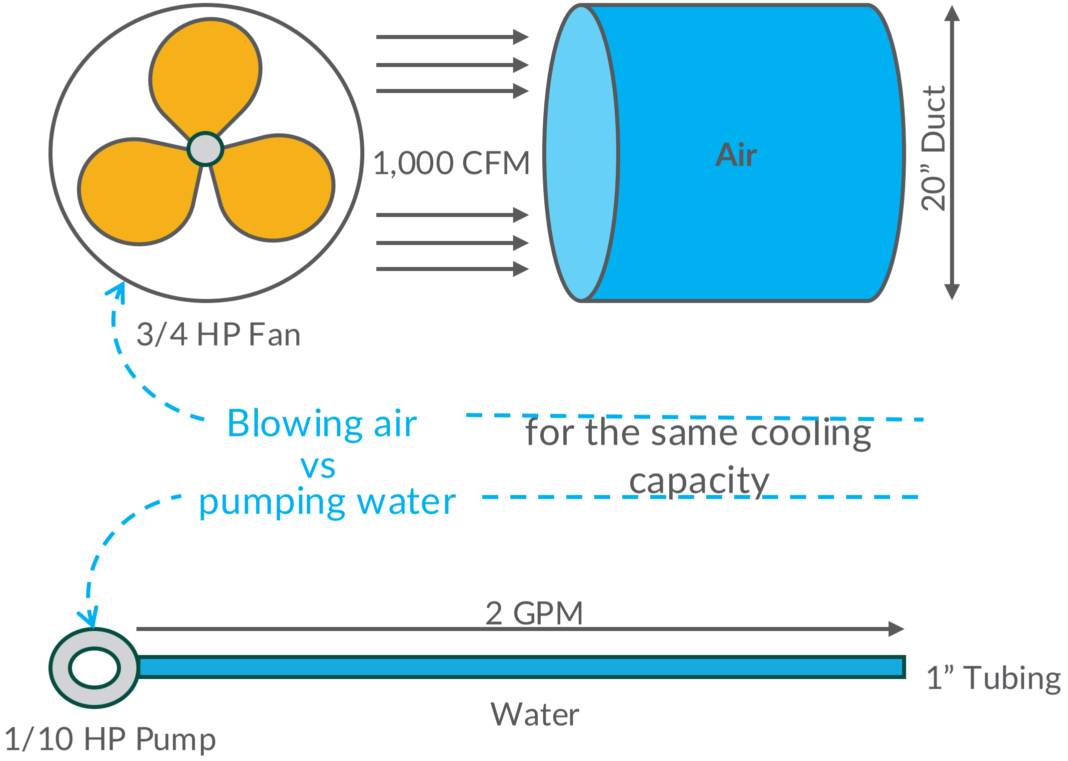
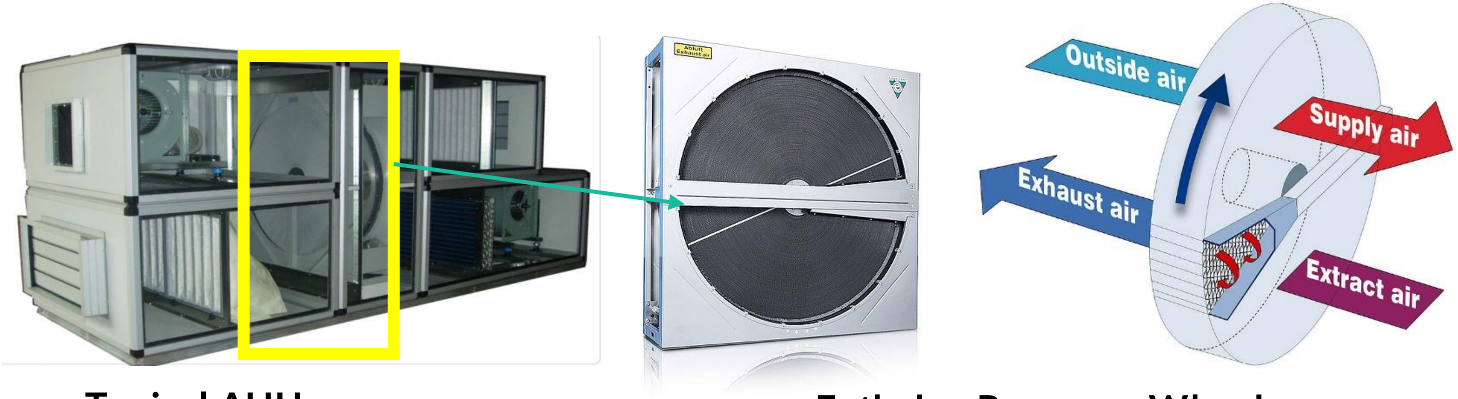


Pumping energy is 7.5 times lower

USE ENTHALPY RECOVERY AT AHU

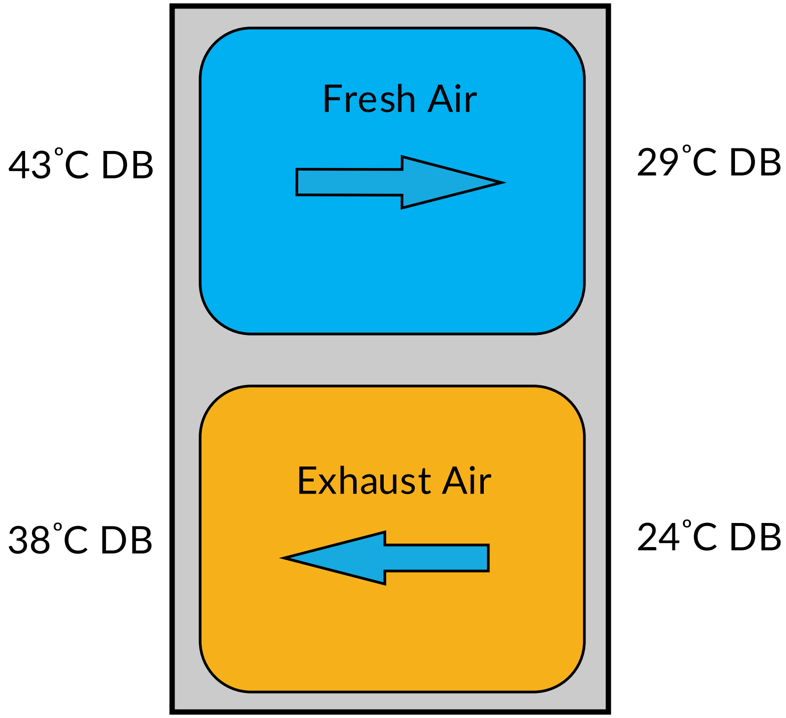
Cooling generated must be recovered to reduce losses

Enthalpy recovery wheel (ERW) recovers both sensible and latent heat



Typical AHU

Enthalpy Recovery Wheel



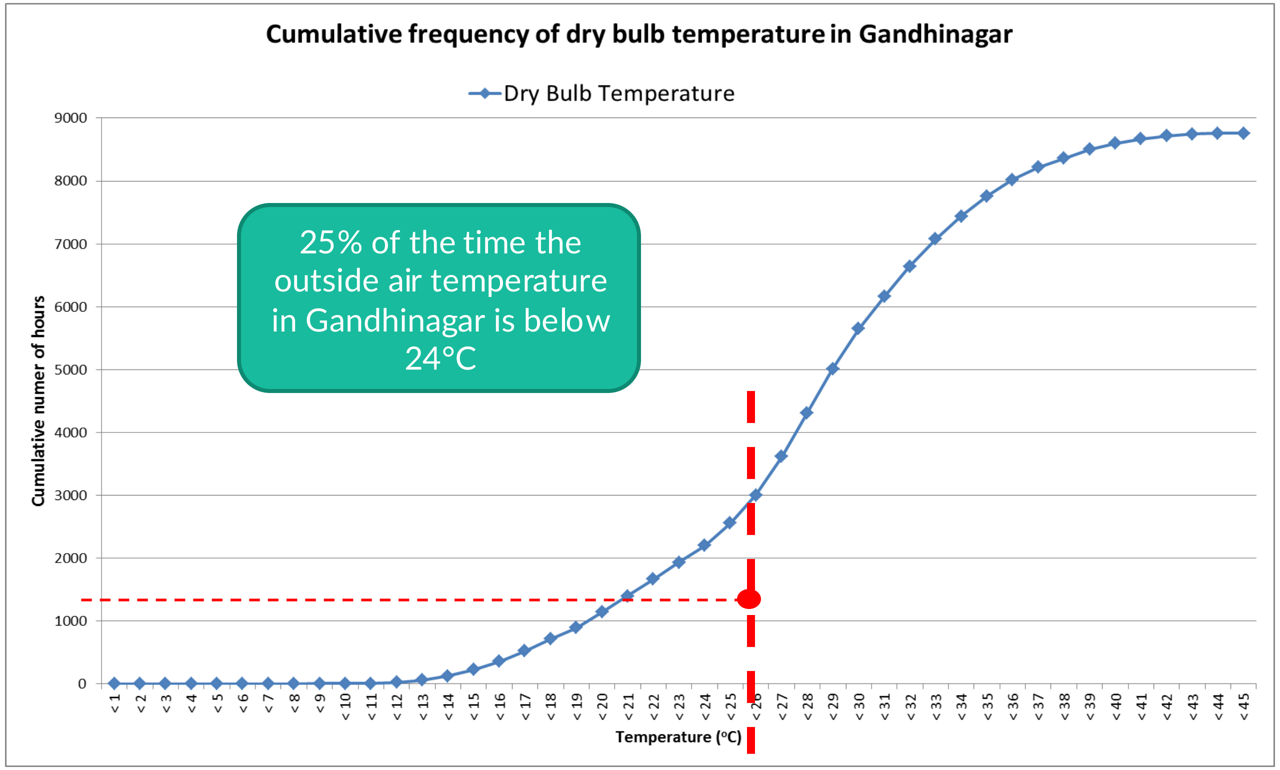
Example of heat recovery wheel: Effectiveness (74%)

The operational energy required for cooling / dehumidifying the fresh air is reduced by using ERW, which is indicated by its effectiveness

FREE COOLING

Provision in air handling unit (AHU)

- Free cooling uses ambient air whenever the temperature and humidity is suitable to cool the building
- Two separate openings are needed in the AHU: one for minimum fresh air and a larger opening for 100% fresh air (free cooling). There should be provision in the AHU to bypass the cooling coil when free cooling is availed
- For optimal utilization, the AHU switching between chiller-based cooling and free cooling should be automated with the use of enthalpy sensors

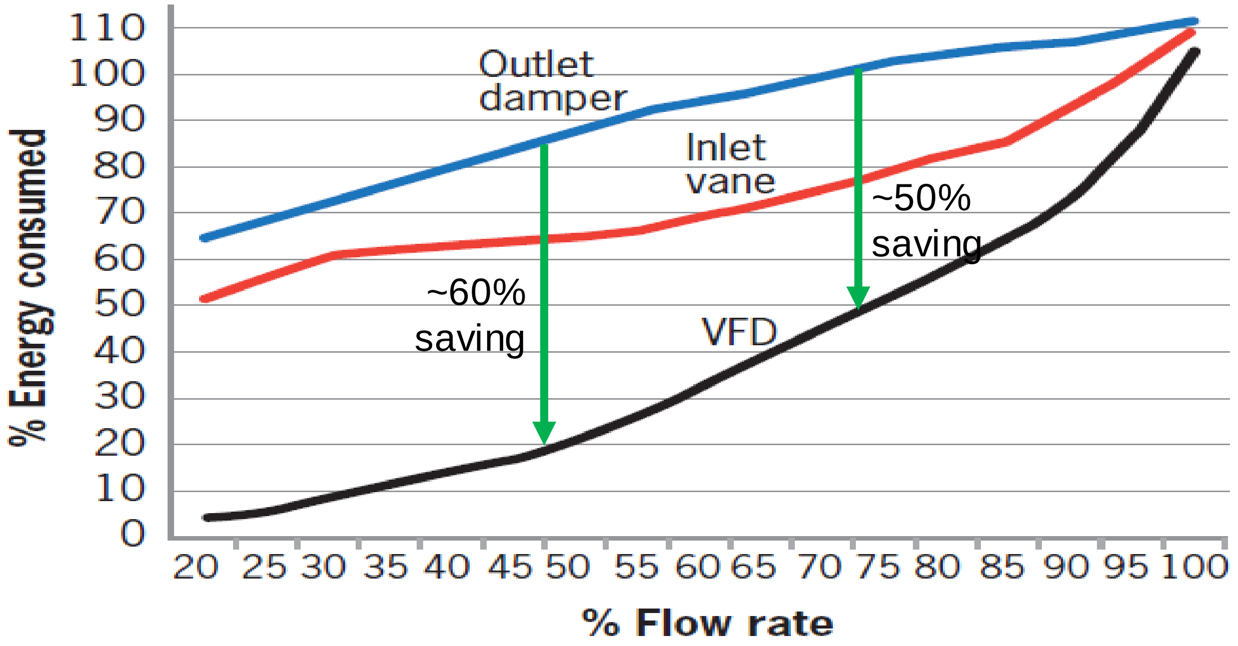


Example: Free cooling potential for Gandhinagar, India

VFD FOR FANS AND PUMPS

Optimize part-load operations

- As the cooling load varies, the water and air flow requirements also vary
- Conventional methods like damper throttling and inlet guide vanes are not efficient methods due to significant throttling losses
- Using VFDs for fans and pumps to meet the varying flow requirement at part loads, can save 50%–60% of energy



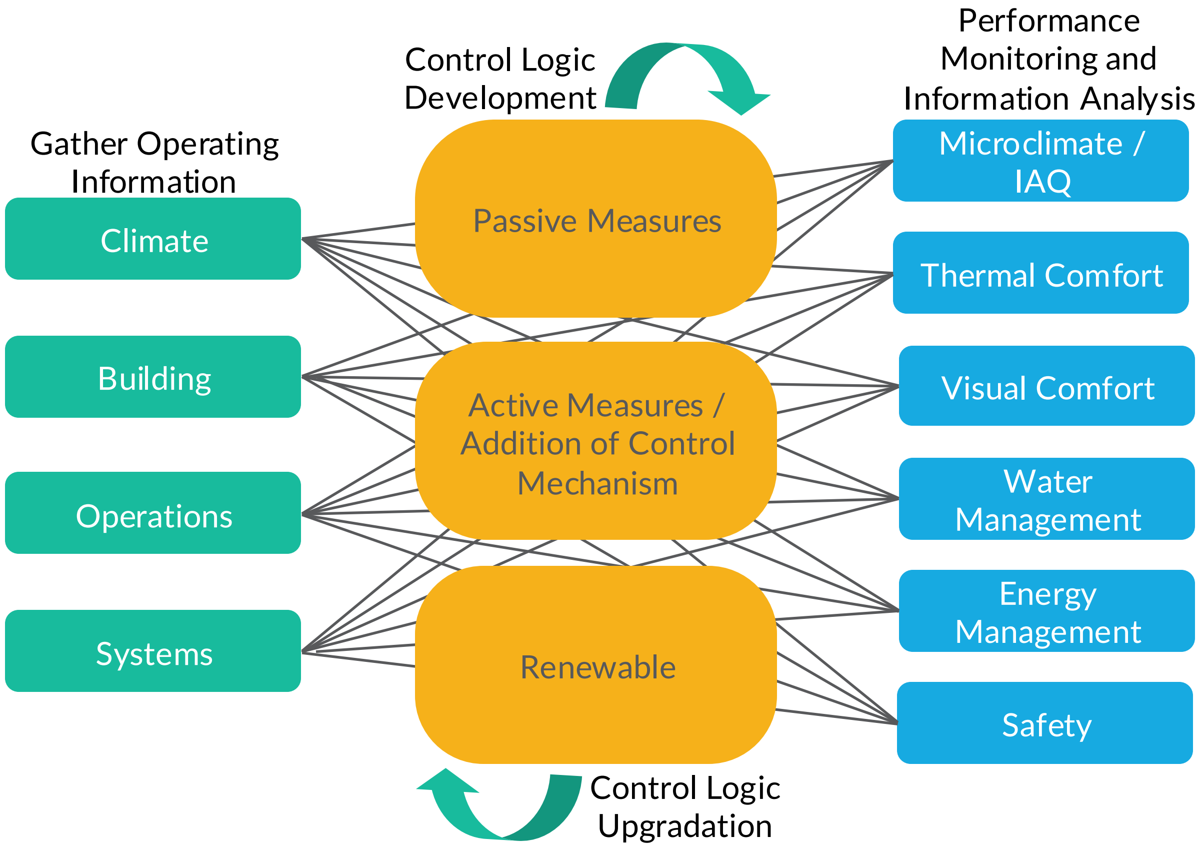
Energy savings with VFDs at lower flows in comparison to damper and IGV controls

Source: Ministry of Power, Government of India, 2022a

BMS CONTROL

For optimizing operational energy

- A building management system (BMS) is a useful tool for optimizing operational energy
- BMS algorithms can simultaneously consider the external factors (climate), and internal factors (operations, occupancy, micro-climate, indoor air quality, thermal and visual comfort), and optimize energy and water consumption
- Now, with artificial intelligence (AI) and machine learning (ML) algorithms, the BMS can automatically reset itself to the best combination
- BMS is useful as historical data and trends can easily be accessed for troubleshooting



Optimizing Other Services

Use of Star-rated Equipment and Appliances

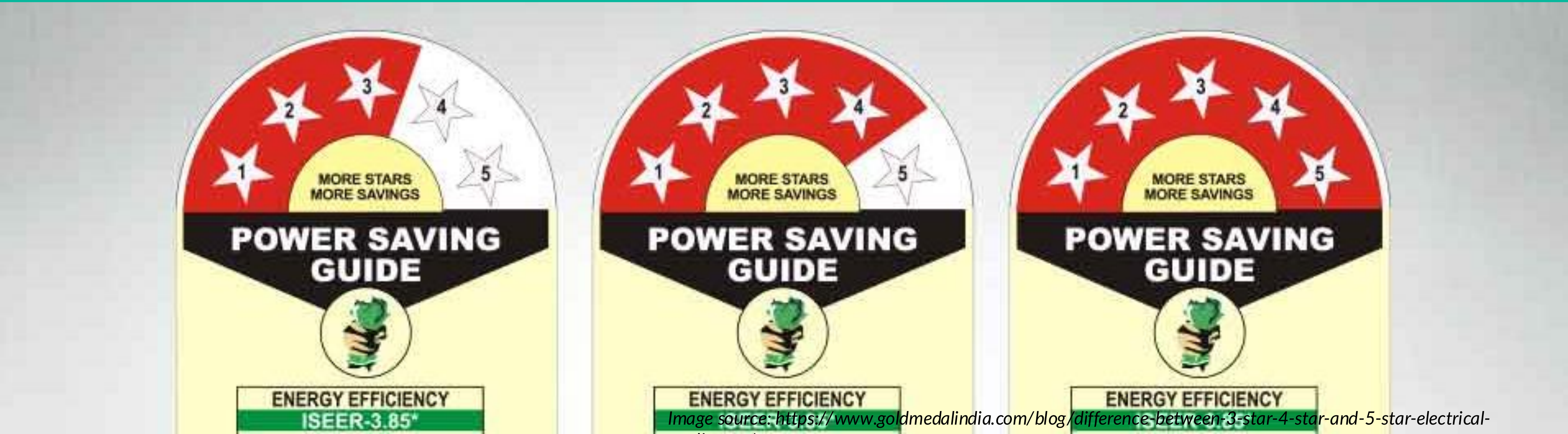


Image source: https://www.goldmedalindia.com/blog/difference-between-3-star-4-star-and-5-star-electrical-

STAR-RATED APPLIANCES

Residential apartment: Savings with energy efficient BLDC ceiling fans

Room Specifications	35W BLDC Fan		70W Capacitor Start Fan	
	Quantity	Operating Hours	Quantity	Operating Hours
Hall	1	12	1	12
BD 01	1	8	1	8
BD 02	1	8	1	8
Kitchen	0	0	0	0
Toilet 01	0	0	0	0
Toilet 02	0	0	0	0
Corridor	0	0	0	0
Installed Power	105W		210W	
Energy Consumed	980Wh		1960Wh	

Source: Bureau of Energy Efficiency, Government of India

STAR-RATED APPLIANCES

Water pumps and heaters: Energy saving potential

Head (m)	Discharge (liters per second)	Rating (kW)	Power Consumption of Unrated Pump Motor (kW)	Power Consumption of 5-star Pump Motor (kW)	Annual Energy Savings (kWh/year)
73	6.67	7.5	11	9	**1,600**
122	6.6	13	17.5	14.5	**2,400**

Capacity of Water Heater (liter)	Standing Losses in Unrated Conventional Water Heater (kW)	Standing Losses in 5-star Rated Water Heater (kW)	Energy Savings (kWh/year)
25	0.823	0.562	65
35	0.940	0.642	75

Source: Bureau of Energy Efficiency, Government of India

STAR-RATED APPLIANCES

Refrigerators

Type	Storage Volume (liter)	Annual Energy Consumption of an Unrated Refrigerator (kWh/year)	Annual Energy Consumption of a 5-star Rated Refrigerator (kWh/year)	Annual Energy Savings (kWh/year)
Frost Free	190	379	155	**224**
	250	400	164	**236**
	300	418	171	**247**
Direct Cool	190	339	138	**201**
	260	346	148	**198**
	310	379	154	**225**

Source: Bureau of Energy Efficiency, Government of India

OTHER SERVICES AND SYSTEMS

Elevators

- **Compliance:** Guideline VDI 4707: Class 1–5 for energy efficiency of lifts
- **Type of motor:** Use of IE3 motor and above
- Use of variable voltage variable frequency drives and regenerative drives
- **Lumen efficacy of lamps used in elevators:** Over 95 lumen/W

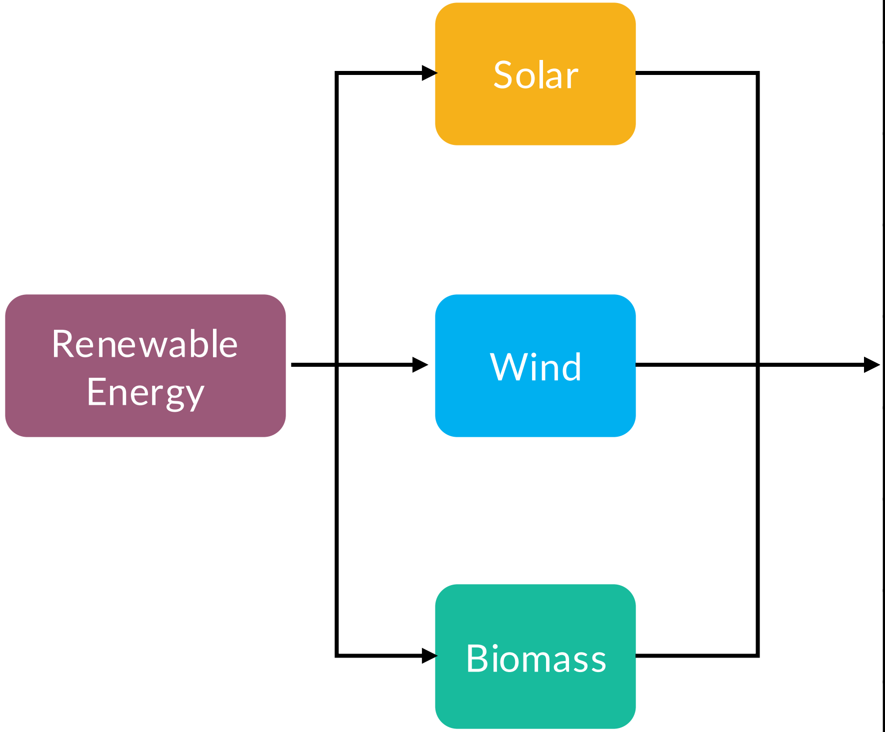
Source: Bureau of Energy Efficiency, Government of India, 2024

Integration of Renewable Energy

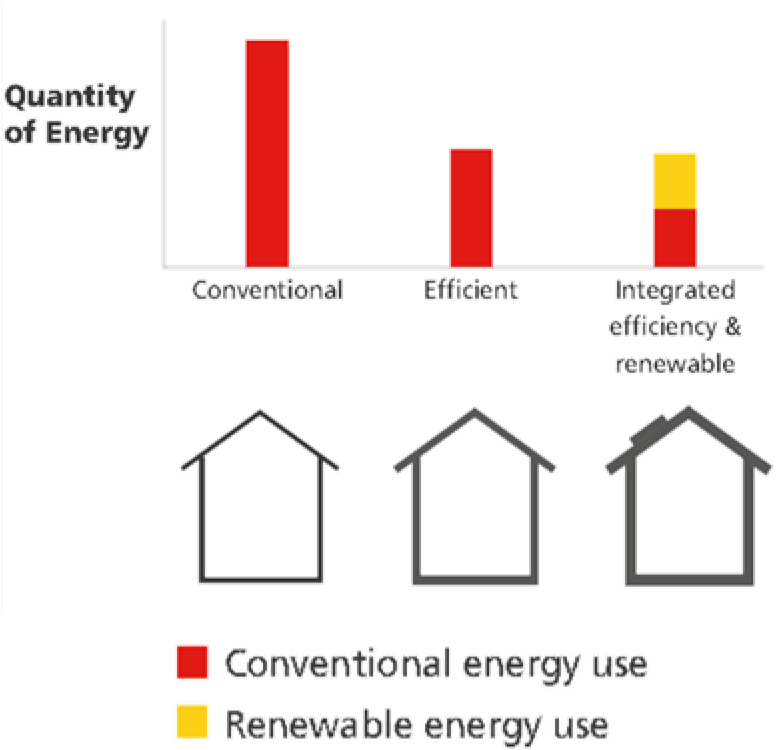
Image source: https://earth.org/the-present-and-future-of-renewable-energy-a-2023-

RENEWABLE ENERGY INTEGRATION

Renewable energy sources



Renewable Energy Technologies
Solar Rooftop (PV and Thermal)
Building Integrated PV Solutions
Hybrid Solar (PV and Thermal)
Small Wind Turbines
Small Wind + Solar Hybrid System
Biomass Energy – Bio Methanation
Heat Pump
Fuel Cells using RE Source as Input



Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation, 2022

RENEWABLE ENERGY INTEGRATION

Photovoltaic (PV) system: Solar electrical power

PV systems fall into two main categories: Grid-connected and off-grid

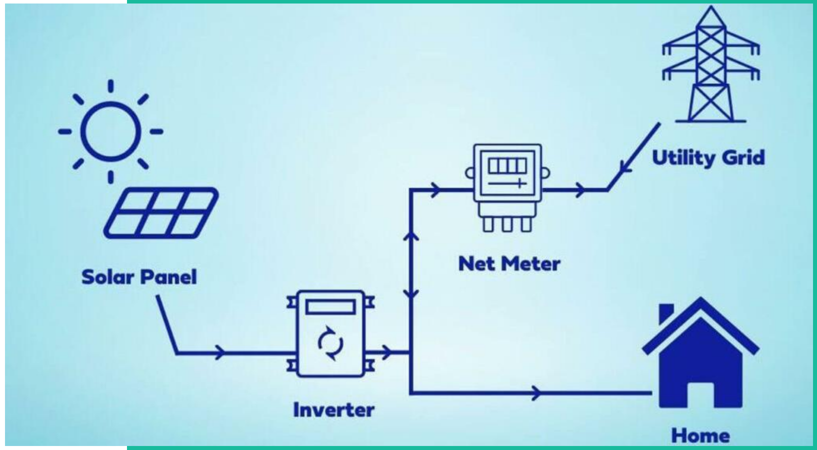
Grid-tied systems:

- The system is connected to the local electricity distribution grid; energy generated is sent to the utility grid
- A credit for the energy generated is provided
- Grid acts as an energy storage unit

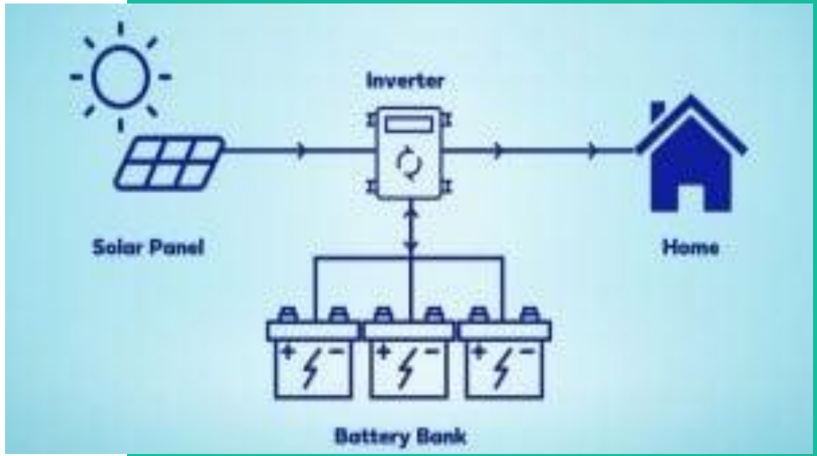
Off-grid systems:

- The system is independent of the local electricity distribution grid
- Energy generated is either consumed in real-time or stored in batteries

Grid-tied System



Off-grid System



Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation, 2022

RENEWABLE ENERGY INTEGRATION

Photovoltaic (PV) system: Solar electrical power

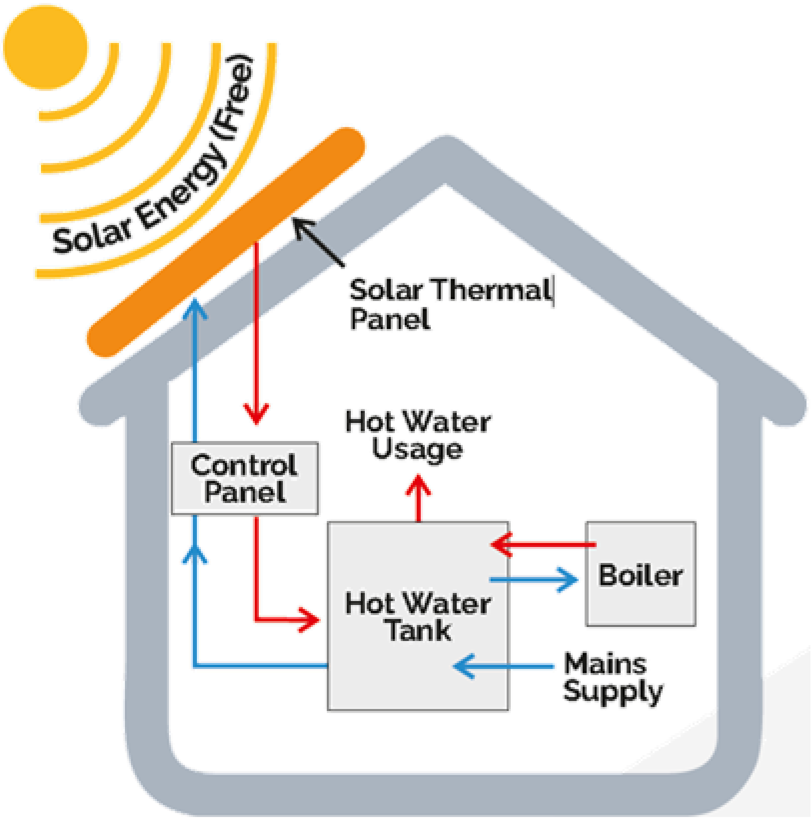
- The rating of the solar panels is given in kilowatts peak (kWp)
- Standard test conditions (STC):
  - Irradiance of 1,000 W/m^2
  - Module temperature at 25°C
  - Solar spectrum of AM 1.5
- As a rule of thumb, 1 kWp system in India generates around 4–5 kWh/day, and requires about 10 m^2 shadow free roof area

Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation

RENEWABLE ENERGY INTEGRATION

Solar thermal system

- A solar thermal system works by harnessing the sun's energy and converting it into heat that is transferred into a home or business heating system as hot water or space heating
- There are two types of solar water heater systems:
  i. Flat Plate Collector
  ii. Evacuated Plate Collector
- A 100-liter capacity solar water heater (SWH) can replace an electric water heater for residential use and save 1,500 units of electricity
- A SWH of 100-liter capacity can prevent the emissions of 1.5 tons of carbon dioxide per year
- The use of 1,000 SWHs of 100-liter capacity each can contribute to a peak load saving of 1 MW
- A 100 LPD solar collector usually has dimensions of 1m x 2m (requiring 3m² rooftop area per collector)

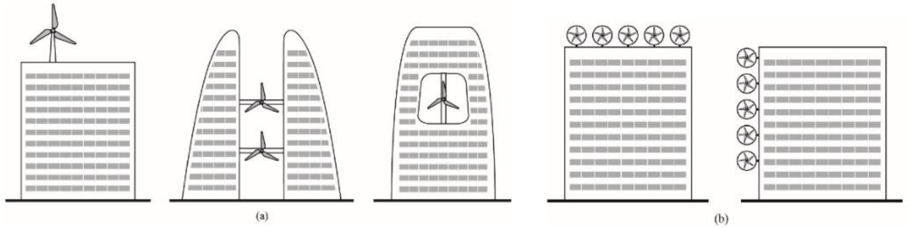


Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation

RENEWABLE ENERGY INTEGRATION

Wind turbines

- Micro wind turbines, called 'building-integrated wind turbines' or 'vertical axis wind turbines' are suitable for building scale applications
- The main components of a wind turbine include blades, rotors, gearboxes and generators
- Vertical axis wind turbine generators (200W–10kW) can be used as standalone systems or as grid-connected systems, and both can be paired with other energy conversion systems, such as photovoltaics
- Wind turbines can generate energy throughout the day and the system does not require frequent cleaning
- The low cut in speed turbines start generating power at 2.5m/s–3m/s wind speed, without creating aerodynamic noise
- The wind turbine should be installed at the highest point of the site where no wind turbulence will be caused by any other building or site elements like trees

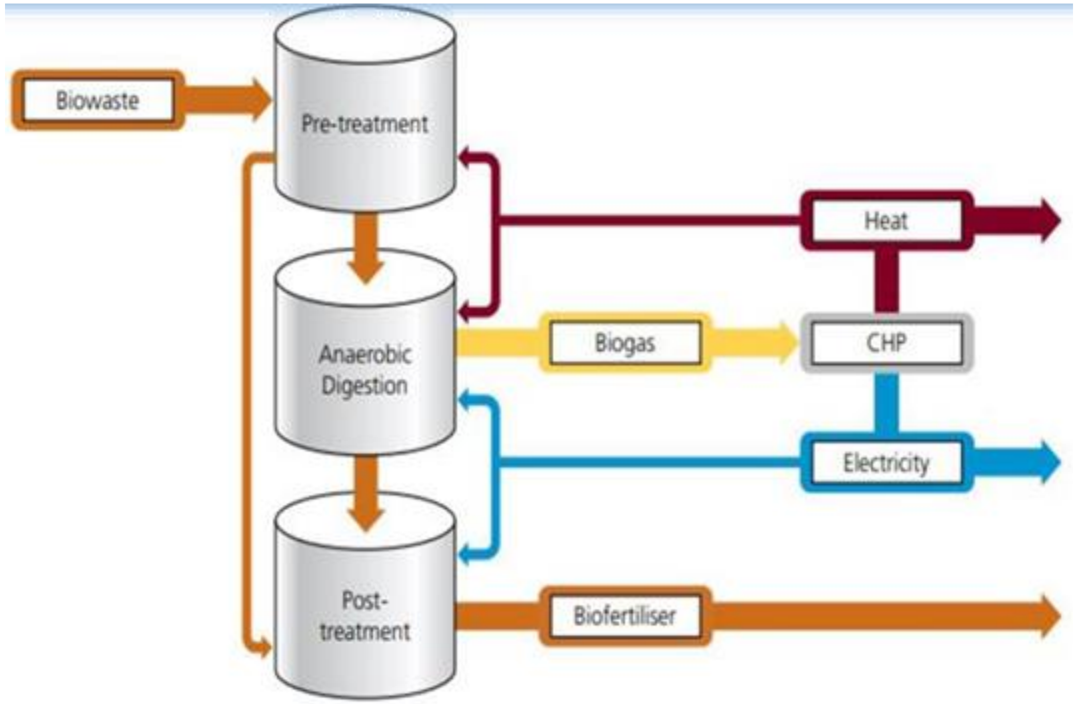


Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation

RENEWABLE ENERGY INTEGRATION

Biomass energy

- Biomass is used for facility heating, electric power generation, and combined heat and power
- The term biomass encompasses a large variety of materials, including wood from various sources, agricultural residues, and animal and human waste
- Biomass can be converted into electric power through several methods:
  - Direct combustion of biomass material, such as agricultural waste or woody materials
  - Gasification of biomass produces a synthesis gas with usable energy content by heating the biomass with insufficient oxygen
  - Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen
  - Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen



Source: Swiss Agency for Development and Cooperation and International Institute for Energy Conservation

Thank you!

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Any person who believes they may be harmed by an IKI project or who wish to report corruption or the misuse of funds, can lodge a complaint to the IKI Independent Complaint Mechanism at IKI-complaints@z-u-g.org. The IKI complaint mechanism has a panel of independent experts who will investigate the complaint. In the course of the investigation, we will consult with the complainant so as to avoid unnecessary risks for the complainant. More information can be found at https://www.international-climate-initiative.com/en/about-iki/values-responsibility/independent-complaint-mechanism/.

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