LAKIREDDY BALI REDDY COLLEGE OF ENGINEERING
(AUTONOMOUS)
Accredited by NAAC & NBA (CSE, IT, ECE, EEE & ME)
Approved by AICTE, New Delhi and Affiliated to JNTUK, Kakinada
L.B.Reddy Nagar, Mylavaram-521230, Krishna Dist, Andhra Pradesh, India

# Department of Mechanical Engineering

## ISHARE STUDENT CHAPTER

**Date: 02 June 2020**

**SPEAKER**

Dr. K V Narasimha Rao
Ph.D (IISc) , F.I.E

Dr K.V. Narasimha Rao is a senior Professional with 27 years of experience in Academic, Consultancy and Industry. He worked for seven years as Research Associate and Fellow in Industrial Energy Group at Tata Energy Research Institute (TERI) and worked as Principal/Director/Dean at various reputed Educational Institutions and has published over 38 scientific papers and numerous technical reports for various National/International Agencies. He specializes in the areas of Energy Auditing, Energy Conservation & Management, Food precooling, Heat Transfer, Refrigeration and Air-conditioning and Renewable Energy Sources

## Qualifications & Awards

- B. Tech. (Mechanical Engg) from Regional Engg College, Warangal – 1986 (now upgraded as NITW)
- M. S. (Engg) by Research from Indian Institute of Science, Bangalore - 1990 (Thermal Engg)
- Ph. D. from Indian Institute of Science, Bangalore – 1995 (Fruit & Vegetable Precooling-Refrigeration & AC)
- 'National Merit Scholarship' Holder during 1979-85 (Six Years) – Top 100 in SSC/Intermediate
- Winner of "Special Prize" at the 'Mathematics Olympiad' during 1981 @ Senior Level.

## Professional Experience

- Teaching & Research – at Vasavi, Hyderabad; IISc, Bangalore & M S R I T, Bangalore – 2 Years
- Industry: Premier Radiators Private Limited, Coimbatore – 1 Year (1994-1995)
- Consultancy & Applied Research – Tata Energy Research Institute, SRC, Bangalore–7 Years [1995-2002]
- Academic & Administration: Sree Vidyanikethan Engineering College, Tirupati; RIT, Yanam; SACET, Chirala; RISE, Ongole; SITS, Khammam; RGMCET, Nandyal & KGRCET, Hyderabad – 14 Years [2002-2016]
- Professor in Mechanical Engg @ KLU since 02-09-2016

## Energy Conservation in HVAC Systems

By

Dr. K. V. Narasimha Rao, Ph. D., F. I. E.
Member: ASHRAE, ISCA, ISHMT, ISHRAE, ISTE & SESI
Professor, Dept of Mechanical Engg and
Associate Dean-Quality
K L University, Green Fields, Vaddeswaram

2 June 2020



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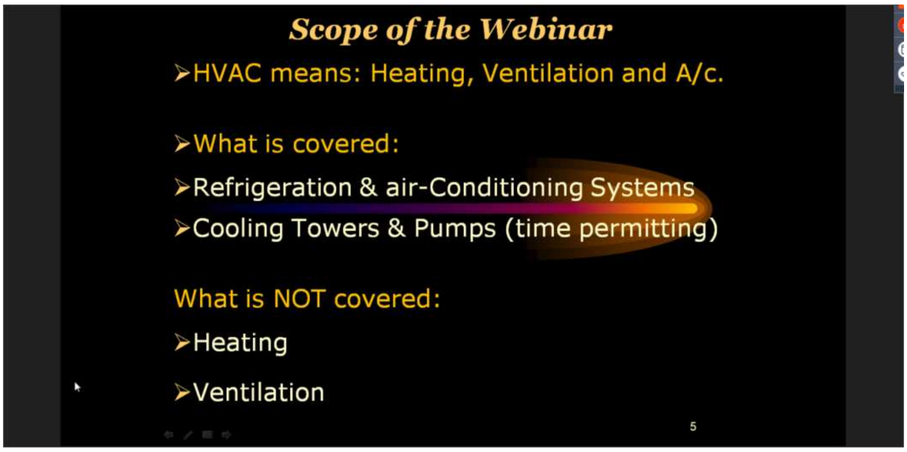
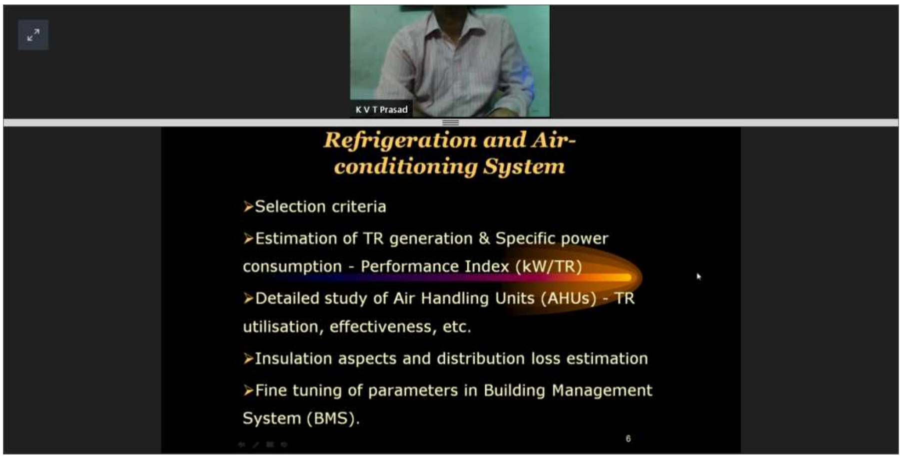
Journey to a thousand miles starts with a single step!

- From Old Testament (or is it an old Chinese proverb?)


Scope of the Webinar
➢HVAC means: Heating, Ventilation and A/c.
➢What is covered:
➢Refrigeration & air-Conditioning Systems
➢Cooling Towers & Pumps (time permitting)
What is NOT covered:
➢Heating
➢Ventilation
5


K V T Prasad
Refrigeration and Air-conditioning System
➢Selection criteria
➢Estimation of TR generation & Specific power consumption - Performance Index (kW/TR)
➢Detailed study of Air Handling Units (AHUs) - TR utilisation, effectiveness, etc.
➢Insulation aspects and distribution loss estimation
➢Fine tuning of parameters in Building Management System (BMS).
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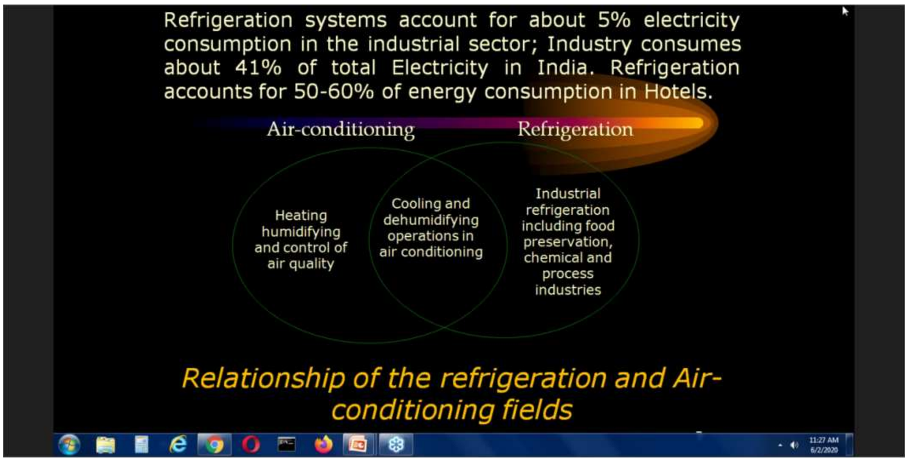
Refrigeration systems account for about 5% electricity consumption in the industrial sector; Industry consumes about 41% of total Electricity in India. Refrigeration accounts for 50-60% of energy consumption in Hotels.
Air-conditioning
Refrigeration
Heating humidifying and control of air quality
Cooling and dehumidifying operations in air conditioning
Industrial refrigeration including food preservation, chemical and process industries
Relationship of the refrigeration and Air-conditioning fields

## Thermal Environmental Conditions for Human Occupancy

*ANSI/ASHRAE Standard 55-2013* gives the thermal comfort conditions as follows:

1. Operative temperature: 20 to 26$^0$C (Summer/Winter)
2. Humidity: A dew point temperature to 2 to 17$^0$C (Equivalent to 33 to 58% RH)
3. Average air velocity: 0.25 m/s (Max: 0.8-1.0 m/s)
4. The air should be clean and odour-free

Note: Clothing and individual metabolism rates do matter.



## *Energy efficiency Ratios*

The cooling effect of refrigeration systems is measured in Tonnes of Refrigeration (TR)

1 TR = 3023 kcal/hour
= 3.517 kW
= 12,000 BTU/hour (refrigeration required to make 1 ton of ice in 24 hours)

The commonly used figures of merit for comparison of performance of refrigeration systems are:

- COP (coefficient of performance)
- EER (energy efficiency ratio)
- kW/TR (specific power consumption)



The performance of refrigeration cycle is usually described by the COP. It is defined as the ratio of amount of heat removed (output) divided by the required energy (input) to operate the cycle.

COP = Useful Refrigeration effect/Net work input

**Most commonly used refrigeration systems:**

- Vapour compression system (PI ~ 0.6-0.9 kW/TR)
- Vapour absorption system (Low grade energy I/p)

**Types of compressors used in VCS:**

- Reciprocating compressors (Very small to 120 TR)
- Screw compressors (about 150 TR - 750 TR)
- Centrifugal compressors (150 TR - very large size)
- Scroll compressors (up to 30 TR)

*Note: Compressor is called the "Work horse/heart" of VCS.*



## *Comparison of the absorption and vapour compressor systems*

- The vapour absorption system can be operated on waste heat.
- In the absorption system, except for two small electrically operated pumps, there are no moving parts. Hence, the absorption system has no vibration and does not need heavy foundation as required in vapour compression system; Less maintenance
- For the absorption machine, the capacity control is stepless whereas the vapour compression system can be controlled in certain steps.



## *Measurements/Field testing*

The parameters needed to be looked into are:

- Inside and outside design conditions
- Measured flows and capacities of all the equipment used in the system (Condensers & Evaporators)
- Comparison of the measured and design capacities
- Comparison of energy consumption with the design values
- Operating head and flow rates of pumps.

**Water flow**

The water flow in a piping system is measured by:

- Taking the pumping head at the discharge and then referring the pump characteristic curves or
- Measuring the flow with a portable non-intrusive ultrasonic flow meter (Expensive: US$10,000)

**Air Flow**

This is calculated by measuring the velocity across a fixed opening having a definite area. The velocity is determined by either measuring the pressure drop across the opening with the help of a pilot tube and manometer OR hot-wire anemometer.



## Temperature/humidity

Two types of temperatures, DBT (dry bulb) and WBT (wet bulb) are measured by:

- Sling psychrometer (Simple, yet useful)
- Electronic thermo-hygrometer (e. g. Testo, Germany)

## Electrical parameters:

Electrical measurements are taken with the help of a portable/fixed power analyzer.



## Cooling tower

The heat rejected at the condenser must match the heat rejected at the cooling tower. The equation for cooling tower is the same as that of the water-cooled condenser. For the cooling tower, the approach should also be evaluated.

The efficiency of cooling tower is defined as:

Range (Water inlet temp. - water outlet temp.) /

Range – Approach (Water inlet temp. - ambient wet bulb temp.)

*Note: When "Approach" becomes zero, efficiency becomes 100%*

## Energy conservation opportunities

- Circulation pumps operation
- Heat exchangers performance (Cond. & Evap.)
- Thermal storage (Time-of-day tariff, if any)
- Cooling tower fan motors
- Installing variable speed drives at AHU fan motors
- Reducing minimum out-door air
- Unoccupied ventilation reduction
- Reducing the heat loads in conditioned spaces (site-specific)



## Switching off Secondary Pump at 360 TR Chiller Unit

The present refrigeration system consists of a 360 TR machine running with primary and secondary pumps. Primary pump will pump chilled water from hot well to cold well through evaporator. Secondary pump is in operation to pump chilled water from cold well to air washer. The measured pressure drop across evaporator is 0.5 kg/cm$^2$, hence primary pump is sufficient to pump chilled water from hot well to air washer through evaporator. Hot well will take care of chilled water flow fluctuation.



| | |
|---|---|
| Design specific power consumption | : 0.90 kW/TR |
| Operating specific power consumption | : 1.58 kW/TR |

### Energy Savings:

| | |
|---|---|
| Reduction in power consumption for present load (63 TR) | : 42.8 kW |
| Annual operating hours | : 8500 |
| Annual energy savings | : 3.64 Lakh kWh |
| Value of savings @ Rs.3.50 per kWh | : Rs. 12.74 Lakh |
| Investment for cleaning 3 chillers | : Rs.6.0 Lakh |
| Simple Payback Period | : 0.5 year |

Suitable mono-block pump for chilled water

| | | |
|---|---|---|
| Make | : | Kirloskar Brothers Ltd. |
| Type | : | KDS-830 |
| Flow | : | 13 lps |
| Head | : | 28 m |
| Power | : | 5.5 kW |
| Overall efficiency | : | 65% |

## Energy Savings

| | | |
|---|---|---|
| Present power consumption of pumps (2&3) | : | 15.5 kW |
| Two mono-block pumps power consumption | : | 11.0 kW |
| Reduction in power consumption | : | 4.5 kW |
| Annual energy savings @8500 per year | : | 38,000 kWh |
| Annual cost savings @Rs.3.00 per kWh | : | Rs.1.14 Lakh |
| Investment for 3 No. monoblock | : | Rs.0.82 Lakh |
| Simple payback period | : | 0.8 year |



The total cooling water flow requirement for VAC and brine chiller can be met by running condenser water pump of VAC.

## Energy Savings

| | | |
|---|---|---|
| Present power consumption of brine chiller pump | : | 11.4 kW |
| Annual energy savings | : | 0.91 Lakh kWh |
| Value of savings @ Rs.3.50 / kWh | : | Rs.3.20 Lakh |
| Investment | : | Marginal |
| Simple Payback Period | : | Immediate |



# *Reduction in Speed of AHU Fan*

The AHU connected to dry powder area (Pharmaceutical Industry) is not utilised fully. Some of the areas connected under this AHU are closed.

| | | |
|---|---|---|
| Measured air flow rate | : | 20736 $m^3/h$ |
| Measured power consumption | : | 3.18 kW |
| Reducing the fan speed | : | 25% (permanently) |

## Energy Savings

| | | |
|---|---|---|
| Reduction in power consumption | : | 1.8 kW |
| Annual operating hours | : | 2400 |
| Annual power savings | : | 4320 kWh |
| Annual cost savings | : | Rs.0.15 Lakh |
| Investment for pulley | : | Rs.0.03 Lakh |
| Simple Payback Period | : | 3 months |

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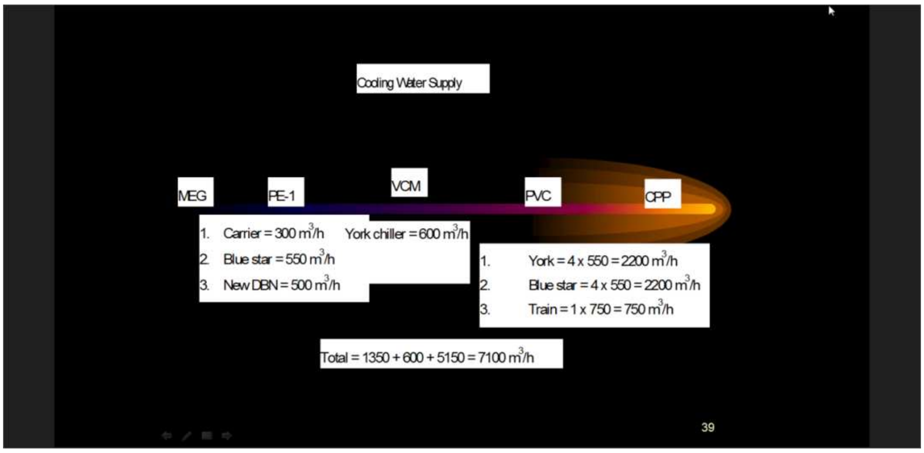
## Installing Separate Cooling Tower for Refrigeration Load

Cooling tower supplies water to meet the cooling water requirement of Phase – I plants. The design approach of cooling tower is 4°C.

- Process cooling water
- Refrigeration condenser cooling water

As the cooling water temperature for process and refrigeration have different requirements of temperature, segregation of them will save energy.





Installing new cooling tower for refrigeration load, one pump of 990 kW (present consumption) can be switched off. Due to new cooling tower with lower approach of 2°C, reduction in refrigeration power consumption can be achieved.

## Energy Savings

| | |
|---|---|
| No. of pumps in operation at CT | : 6 |
| Total supply cooling water flow | : 35,000 $m^3/h$ |
| Each pump design flow, head | : 5,500 $m^3/h$, 50 m |
| Power consumption of one pump | : 990 kW |
| Refrigeration condenser cooling water flow (excluding new DBN) | : 6,600 $m^3/h$ |



## Pumping power required at proposed cooling tower

| | | |
|---|---|---|
| Cooling water flow rate | : | 6600 $m^3/h$ |
| Head required | : | 32 m (max.) |
| Efficiency of pump | : | 88% |
| Efficiency of motor | : | 95% |
| Expected power consumption | : | 688 kW |
| Reduction in pumping power consumption | : | 990-688 = 302 kW |
| Annual operating hours | : | 8700 |
| Annual energy savings | : | 26.27 lakh kWh |
| Value of energy savings | : | Rs.65.69 lakh |
| Cost of implementation | | |
| New pumps (4 Nos.) | : | Rs.40 lakh |
| Cooling tower for 12000 TR | : | Rs.85 lakh |
| Simple payback period | : | 1.9 years |

*Note: In the above proposal reduction in power consumption of refrigeration power is not considered, which is nearly 120 kW (10 lakh kWh per annum, i. e. Rs. 26 lakh)*



# Cooling Towers

- Cooling Tower is the most important Off-site Utility – usually treated as an Orphan
- Analyses of operating range and approach [Range: Inlet temp. – Outlet temp. of water]
- Cooling tower optimization
- High efficiency (lightweight) aero foil fans
- Automatic temperature controller

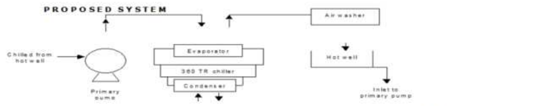
## Replacing present chilled water pumps with mono-block pumps at 60 TR chiller

Efficiency evaluation of present pumps

| Parameters | Unit | Design | Pump # 2 | Pump # 3 |
|---|---|---|---|---|
| Flow rate | lps | 11.36 | 13.5 | 8.5 |
| Head | m | 30 | 30 | 30 |
| Power | kW | 5.66 | 8.73 | 6.84 |
| Pump efficiency | % | 59 | - | - |
| Motor efficiency | % | 88 | - | - |
| Overall efficiency | % | 52 | 45.5 | 36.5 |

Variation in flow is due to parallel operation



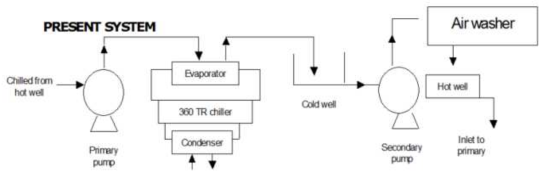



Primary pump delivery pressure : 3.5 kg/cm$^2$
Pressure drop across evaporator : 0.5 kg/cm$^2$
Pressure at the nozzles of air washer : 2.8-3.0 kg/cm$^2$

**Energy Savings**

Power consumption of secondary pump : 27.6 kW
Annual energy savings : 2.35 lakh kWh
Annual cost savings : Rs.7.05 lakhs
Investment required : Rs.1.5 lakhs
Simple payback period : 3 months






Primary pump delivery pressure : 4.5 kg/cm$^2$
After throttling pressure : 1.2 kg/cm$^2$
Secondary pump delivery pressure : 3.5kg/cm$^2$
Pressure drop across evaporator : 0.5 kg/cm$^2$

***Improving "TR" Generation of 110 TR Refrigeration System***

*The 110 TR refrigeration system is not performing as per design. Even by pumping rated flow rate of chilled water, difference in temperature across chiller and condenser is not achieved.*

***Comparative Analysis of 110 TR Operating Vs Design***

| Parameters | Unit | Design | Actual |
|---|---|---|---|
| Capacity | TR | 110 | 63 |
| Input power | kW | 100 | 99.5 |
| Chilled water flow | lpm | 1287 | 1590 |
| Condenser water flow | lpm | 1477 | 2490 |
| ΔT across chiller | °C | 4.3 | 2.0 |
| ΔTacross condenser | °C | 4.6 | 1.8 |

# Effect of variation in evaporator temperature on compressor power consumption

| Evaporator temp. (°C) | Refrigeration capacity (tonnes) | Specific power consumption (kW/tonne) | Increase in kW/tonne) |
|---|---|---|---|
| 5.0 | 67.58 | 0.81 | - |
| 0.0 | 56.07 | 0.94 | 16.0 |
| -5.0 | 45.98 | 1.08 | 33.0 |
| -10.0 | 37.20 | 1.25 | 54.0 |
| -20.0 | 23.12 | 1.67 | 106.0 |

Condenser temperature at 40 °C

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| 0.0 | 56.07 | 0.94 | 16.0 |
| -5.0 | 45.98 | 1.08 | 33.0 |
| -10.0 | 37.20 | 1.25 | 54.0 |
| -20.0 | 23.12 | 1.67 | 106.0 |

Condenser temperature at 40 °C



# Effect of variation in condenser temperature on compressor power consumption

| Condensing temperature | Refrigeration capacity (tonnes) | Specific power consumption | Increase in kW/tonne (%) |
|---|---|---|---|
| 26.7 | 31.5 | 1.17 | - |
| 35.0 | 21.4 | 1.27 | 8.5 |
| 40.0 | 20.0 | 1.41 | 20.5 |

Evaporator temperature at –10° C