APPENDIX A

PhD QUESTIONNAIRE
PhD QUESTIONNAIRE

Dear respondent I, Shankar Vasant Kadam, am a Ph.D. student of the D.Y.Patil University, (Faculty of Management). The title of my Ph.D. Research is “A STUDY OF ENERGY MANAGEMENT AT PLANT LEVEL UTILITIES WITH SPECIAL REFERENCE TO SELECTED INDUSTRIES.” I request you to kindly extend your co-operation with your genuine responses, and contribute in bringing awareness about the effective and efficient Energy Management. All data will be only for academic purpose only.

GUIDELINES FOR THE RESPONDENT:

1) Read each statement carefully. Kindly do not evaluate the statement. After reading the statement give your free and frank opinion by giving an appropriate response to each statement. ( ✓ Tick mark whichever is applicable)

2) Each statement is provided with various alternatives / options / blank lines for your views, opinions and suggestions ( please write)

3) When answering the following questions please feel free to add any extra information that you think may be of interest to my research. There is additional space at the end of the questionnaire for you to do so.

4) All responses to this questionnaire are for research purposes only. By completing this questionnaire you are consenting to the use of your data for this purpose. You will remain anonymous and no identifying personal details will be used in any published findings.

- Each completed questionnaire will contribute significantly to my PhD research.
- The questionnaire has been piloted and will take around 15 minutes to complete.
- Thank you for your time and interest.
(SELF ASSESSMENT TEST)

Information of your industrial unit

1. Name of the Employee : _______________________________
2. Designation : _______________________________________
3. Contact Number : _____________________________________
4. E-mail Address : _____________________________________
5. Name of Company / Firm / Unit : _______________________
6. Address : ___________________________________________
   _____________________________________________
7. Year of Establishment : _________________________________

(✔ Tick mark whichever is applicable)

1. Which of the following Energy Management Techniques you have adopted to Conserve energy at plant level utilities?

   □ Installation of variable frequency drives wherever required.
   □ Practice of turning of electrical power when not needed.
   □ Efficient sizing of electrical distribution system
   □ Installation of multistage Air Compressors
   □ Optimization of Compressed air velocity in the pipe work
   □ Installation of Energy Efficient lamps.
   □ Conducting power quality audit from the external professional agencies.
   □ Cooling tower blow down optimization.
   □ Changing the set points of chiller as per the variation in the requirements.
   □ Trimming the impeller of the centrifugal pumps to reduce the excessive pressure.
Designating a position accountable for overseeing and coordinating energy conservation activities.

Displaying a policy which states organization’s philosophy on Energy Management

Formation of Energy Management Cell.

Displaying awareness posters at the strategic locations in the plant.

Please specify if you adopted any other Energy management technologies and techniques apart from the above?

1) ________________________________

2) ________________________________

3) ________________________________

4) ________________________________

2. Are you practicing a Standard Procedure (SOP) for calculating per unit cost of the following utilities?

<table>
<thead>
<tr>
<th>Remarks</th>
<th>Compressed Air</th>
<th>Chilled Water</th>
<th>Treated Water</th>
<th>Hot water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If yes, what is the frequency of practice of utilities cost calculation?

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Quarterly</th>
<th>Six-monthly</th>
<th>Yearly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chilled Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. (a) Do you receive the demand for utilities requirement in advance?

(b) If ‘yes’, how frequently you get the demand information?

<table>
<thead>
<tr>
<th>Shift wise</th>
<th>Daily</th>
<th>Weekly</th>
<th>Fortnightly</th>
<th>Monthly</th>
</tr>
</thead>
</table>

4. Do you generate and supply the utilities exactly matching with user end?

5. Do you think that there is scope to optimize utilities generation and demand sides?

6. Which of the following barriers to Energy Efficiency do you think are more critical and needs to be addressed in your industry?

- Lack of awareness about Energy Conservation among the employees.
- Inadequate training programs on Energy Management.
- Management concerned about investment costs of Energy Efficiency Measures.
- Limited access to and availability of technical information.
- Difficulty in obtaining financing for Energy Efficiency Projects.
- Limited financial incentives by Government for energy efficiency.
- Production is given more importance.
- Lack of Certified Energy Auditor/Manager in the organization.
- Lack of Energy Audits at periodic intervals.
Please specify any other barriers to Energy Efficiency in your plant other than above –

1) _______________________________________________________________
2) _______________________________________________________________

**ELECTRICAL SYSTEM**

7. Do you think that there is scope for replacing higher wattage lamp with lower wattage lamps at certain places in your plant?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

8. Have occupancy sensors been installed in intermittently occupied rooms?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

9. Is there any Certified Energy Auditor in the company who is accountable for carrying out energy conservation activities?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

9a. Do you conduct Energy Audit with external professional agencies?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

10. If yes, at what frequency you conduct Energy Audit with external agencies?

<table>
<thead>
<tr>
<th>Quarterly</th>
<th>Half-Yearly</th>
<th>Yearly</th>
<th>Every 2 years</th>
<th>More than two years</th>
</tr>
</thead>
</table>

**WATER SYSTEM**

11. Is there any scope to replace existing water taps with sensor taps for all the washbasins?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>
12. Have you installed waterless urinals in your toilets?  

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

13. Are you using treated sewage water for cooling tower make up?  

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

**HVAC (HEATING, VENTILATION AND AIR CONDITIONING) SYSTEM**

14. Have you installed Auto Tube Brushing (ATB) online descaling system on chiller condenser?  

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

15. Have you installed two speed motors for ventilation units?  

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

**COMPRESSED AIR SYSTEM**

16. Do you carry compressed air leakages survey with ultrasonic leak detector?  

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

17. If yes, please specify the frequency of testing air leakages in the plant with ultrasonic leak detector?  

<table>
<thead>
<tr>
<th>Monthly</th>
<th>Quarterly</th>
<th>Half-yearly</th>
<th>Yearly</th>
<th>More than one year</th>
</tr>
</thead>
</table>
18. Have you made any provisions to reduce the inlet air temperature of air compressor?

| YES | NO |

19. If yes, what is the difference between ambient temperature and air compressor intake air temperature?

<table>
<thead>
<tr>
<th>2°C</th>
<th>4°C</th>
<th>6°C</th>
<th>8°C</th>
<th>More than 10°C</th>
</tr>
</thead>
</table>

20. Are your compressors operating on partial load?

<table>
<thead>
<tr>
<th>Always</th>
<th>Offtenly</th>
<th>Intermediately</th>
<th>Sometimes</th>
<th>Rarely</th>
</tr>
</thead>
</table>

21. Do you think that there is a scope to replace few of the existing pneumatically operated tools with electrically operated tools?

| YES | NO |

22. Have you installed air controller system on your compressed air system to supply the Compressed air exactly at the required pressure as per different user requirements?

| YES | NO |

**HOT WATER SYSTEM**

23. Have you installed online flue gas analyzer on Hot Water Generator?

| YES | NO |
24. Do you have a standard procedure (SOP) in your plant for assessing performance and operational efficiency of the following critical Equipments?

<table>
<thead>
<tr>
<th>Remarks</th>
<th>Air Compressor</th>
<th>Chiller</th>
<th>Cooling Tower</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

25. If yes, at what frequencies you are assessing the performance and efficiencies of the following utility Equipments?

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Air Compressor</th>
<th>Chiller</th>
<th>Cooling Tower</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quarterly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Six-Monthly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once in two years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

26. Are training programs conducted on Energy Management Tools and Techniques in your plant for employees?

<table>
<thead>
<tr>
<th>Remarks</th>
<th>Air Compressor</th>
<th>Chiller</th>
<th>Cooling Tower</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

27. If yes, how many training programs were organized in last one year on Energy Management in your plant?

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Air Compressor</th>
<th>Chiller</th>
<th>Cooling Tower</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
28. How many number of training programmes you have attended on Energy Management during last one year?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th>More than 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

29. Do you think that additional training programs should be conducted on Energy Management?

<table>
<thead>
<tr>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
</table>

30. Rank the priority for the energy management training needs of the following utilities –

In range of 1-5,

1 – Very low Priority, 2-Low Priority, 3- Medium Priority, 4 – High Priority, 5 – Very High Priority

<table>
<thead>
<tr>
<th>Electrical System</th>
<th>Water System</th>
<th>Compressed Air Conditioning</th>
<th>Hot water Generation System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Signature of Respondent : ___________________________ Date : ___________________________

THANKS FOR YOUR FEEDBACK
RESEARCH PAPERS PUBLISHED

The following Research papers are published in the following ISSN Journals:


ABSTRACT

Some industries improve their energy efficiency and others don’t or lag behind. The reason behind this is that the Industries are faced with a range of financial, cultural, technical and external barriers that affect their ability to adopt energy efficiency technologies. The question arises here is what are those barriers and how can we overcome these barriers?

This paper incorporates the investigation of barriers for the implementation of energy efficient technologies in Industrial utilities to shed light on the rationale for non-adoption of cost effective industrial energy efficient technologies. The study was carried out as part of doctoral research work on energy management industrial utilities. This study was carried out using a structured questionnaire. Respondents were asked to respond about barriers in their respective industries in implementation of energy efficient technologies in utilities.

The study reveals that the important barriers impeding the implementation of cost effective energy efficient technologies in utilities in the surveyed firms are inadequate training programs on energy management and lack of awareness about energy conservation among the employees. In addition to this, majority of the respondents reported that production/manufacturing is given more importance and adequate importance is not being given to energy conservation.

KEYWORDS: Barriers to Energy Efficiency, Energy Efficient Technologies
ABSTRACT

For any Entrepreneur, Energy today has become a key factor in deciding the product cost at micro level as well as in dictating the inflation and the debt burden at the macro level. Energy cost is a significant factor in economic activity. Energy Audit attempts to balance the total energy inputs with its use and serves to identify all the energy streams in the systems and quantifies energy usages according to its discrete function. Energy Audit is a tool to identify areas where energy consumption or wastage of Energy is taking place. An Energy Audit involves measuring the actual energy used in the plant, comparing it with an estimate of the minimum energy required to undertake the process and establishing technically and economically feasible means to achieve the same. It is an established fact that, a properly executed energy audit can bring forth potential for savings of the order of 2 to 20% in an average Indian Industry. The paper talks about the objective, types, methodology, benefits, application of energy audit with an example. This will help an Entrepreneurship/Industry to understand and implement an Energy Audit for Energy Management and Efficiency in the plant.

KEYWORDS:

Energy Audit, Energy Management, Energy Efficiency
OPPORTUNITIES FOR ENERGY EFFICIENCY IN INDUSTRIAL UTILITIES

By: - SHANKAR VASANT KADAM

Certified Energy Manager

Institute: Dr.D.Y.Patil Vidyapeeth, Pune.
Contact Details: shan_kad@yahoo.co.in
Guided By: - Dr. D.D.Balsaraf

ABSTRACT

Without Energy we do not simply think about our modern life. Generation of Energy requires natural resources which are depleting day by day. On the other side, use of energy is increasing exponentially. In developing nation like India, about 49% of energy of total energy consumption takes place in industries only and in industries, utilities like Compressed Air, Air Conditioning, Steam, Hot water, Electrical systems, fuel, water system consumes substantial part of total energy almost 50% and more. Thus the need to improve and maintain energy efficiency of Industrial utilities is strongly felt to survive in present scenario of rising energy costs and volatile energy markets and to gain competitive advantage.

There are two options to match the pace of industrial development. First one is to produce more and more industrial energy which is quite difficult considering depleting natural resources and second one is to reduce the consumption of energy by improving energy efficiency of industrial utilities. Paper focuses on reducing energy consumption of utilities through effective energy management tools and techniques.

APPENDIX C

LIMITATIONS OF THE STUDY

For any study, it is very ordinary course that a student gains scope but faces some limitations also. Such limitations are on account of temporal factors, subject matter, context, characteristics of population and sample etc.

This study is quite motivating since it has longer life as a research problem and very pertinent in Indian economic environment. However the limitations are not making the study redundant and as normal as any student of social research generally faces.

The following are the major limitations of the study:

1. Due to confidentiality of the data, the research was focused more on qualitative data rather than quantitative data.

2. Restricted access to shop floor made the study more focused on primary data.

3. Considering technical and managerial aspects of the study, only utility engineers and managers were included in the sample.

4. Temporal scope was restricted to automobile industries manufacturing passenger cars in Pune because of the widespread number of industries.

Despite of limitations, all necessary efforts are made to overcome the above difficulties by intensifying the frequency of visits and building excellent rapport with all the respective respondents included in the sample.
SCOPE FOR FURTHER RESEARCH

1. This research will be helpful to adopt best energy conservation measures. However, payback period, internal rate of return on investment on energy conservation projects can be calculated and studied before implementing energy conservation project.

2. For a nation like India where internal resources are limited and external resources are costly and uncertain, the future lies in renewable energies and energy efficiency. Similar study can be done for Renewable Energy Resources like Solar and Wind energy to find out status and scope for their implementation in industries.

3. Energy conservation study can be done in manufacturing area to study specific utilities consumption per unit of product.

4. To get trends and patterns in this area, longitudinal research can be adopted. This research was limited to only one area, i.e. Pune. More geographical coverage may enlighten few other facts and findings also.

5. An essential extension of this research work will be to incorporate the views of external stakeholders like researchers, equipment dealers, financial organizations, local government, trade associations/ unions and many more on the barriers and drivers for improving industrial energy efficiency.

By so doing, claims made by respondents could be supported or refuted and an additional broad base knowledge suitable for policy implementation will be developed. Lastly, studies could be narrowed down to high-energy intensive and low energy intensive firms.
IMPACT OF RESEARCH AND MANAGIRIAL IMPLICATIONS

The research will contribute to the existing knowledge from the theoretical and practical perspective. Concerning the contribution to the scientific theory, even though the presented literature review in description of the research topic area indicates the absence of articles published in the field most of the research area.

Some of the scientific papers published by now have been theoretical, giving principal ideas of energy management, but there hasn’t been any research done especially in India, that would deal with status of energy management, Performance Assessment of utility equipment, Utility Costing, Training needs of energy management, Barriers in adoption of Energy Efficient Technologies in industries. The present research was focused on these critical areas.

As discussed earlier, energy demand is increasing day by day and to meet that demand is very difficult in present scenario. Only way is to manage energy effectively and efficiently to reduce energy consumption. The study will be helpful for Globe, Nation, Researcher and industries in major.

A. For Globe,
   1. Reduced GHG and other emissions.
   2. Maintains a sustainable environment.

B. For Nation,
   1. Reduced energy imports.
   2. Avoided costs can be used for poverty reduction.
   3. Conservation of limited resources.
   4. Improved energy security.
   5. Helps while making energy management policies.
C. For Researcher,
1. Forms a basis for further research to identify specific utilities consumption/cost per unit of product.
2. It will help researchers to study energy management in manufacturing processes in industries.
3. Similar study can be undertaken for renewable energy resources with reference to present study.

D. This study will help industries to:
1. Adopt most Energy Efficient Technologies in utilities.
2. Reduce overall energy consumption, thereby reducing energy bills.
3. Achieve targeted energy savings thereby avoiding penalties.
5. Selecting most energy efficient utility equipment.
6. Increased Competitiveness.
7. Increased productivity.
8. Increased profits.

9. Researcher has developed procedure for “Energy performance Assessment of Utility Equipment” which will help industries to assess the energy performance of major utility equipment and to take corrective action against deficiency.

10. Procedure developed to calculate the generation cost of utilities will definitely help industries to create awareness among the employees and to control the generation cost.

11. Researcher has also identified the potential barriers in adoption of energy efficient technologies and suggested various actions to overcome these barriers. This would help industries to implement energy efficient technologies in their plant.
12. Training needs of the employees identified by the researcher with respect to energy management in utilities would help industries to plan and develop training programs to create awareness and enhance technical and managerial capabilities so as to implement energy management systems effectively and efficiently.

13. Present Energy management study can be applied to Automobile, Pharma, Steel, and Utility Industries in major.

14. Electricity generation requires fuels like coal, oil etc. which leads to significant emission of polluting gases. So energy management will reduce pollution.
APPENDIX F

COST OF THE RESEARCH

Equipment used for the research

a) Computer
b) Printer
c) Scanner
d) Internet dongle
e) Xerox Machine

Cost of the research is as given below:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Items</th>
<th>Estimated Expenditure in INR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fees</td>
<td>1,50,000</td>
</tr>
<tr>
<td>2</td>
<td>Hiring services</td>
<td>25,000</td>
</tr>
<tr>
<td>3</td>
<td>Field work and travel</td>
<td>45,000</td>
</tr>
<tr>
<td>4</td>
<td>Contingency (Including special needs)</td>
<td>25,000</td>
</tr>
<tr>
<td>5</td>
<td>Books and Journals</td>
<td>18,000</td>
</tr>
<tr>
<td>6</td>
<td>Printing and stationary</td>
<td>14,000</td>
</tr>
<tr>
<td>7</td>
<td>Equipment</td>
<td>12,000</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>2,89,000</strong></td>
</tr>
</tbody>
</table>

In words: Two Lakhs and Fifty Nine Thousand only
APPENDIX G

PHOTOGRAPHS

Air Compressor – (Screw)

Air Compressor (Centrifugal)
Chiller

Cooling Tower
Body shop of an Automobile Plant

Assembly shop of an Automobile Plant
Sensor Faucet

Waterless Urinal
PERFORMANCE ASSESSMENT OF AIR COMPRESSOR BY RECEIVER FILLING METHOD

1. Procedure:
1.1. Close the outlet valve and inlet valve of air receiver.
1.2. Drain the compressor air receiver and ensure that the pressure is zero.
1.3. Start the air compressor and note down the time of loading the compressor.
1.4. Note down the time when the air pressure in the receiver reaches at 10 Kg/cm². (Unloading pressure may vary depending upon the design pressure rating of the particular Air Compressor.)
1.5. Calculate the efficiency of the air compressor as per the following formula:

\[ \text{Efficiency} (\eta) = \left( \frac{Cc * 100}{Dc} \right) \]

Capacity, \( Cc = \left( V * (P2-P1)/Pa*T \right) \]

\( V1 \) = Volume of receiver in M³.
\( V2 \) = Net volume of pipes from compressor to receiver in M³.
\( V \) = Total volume (\( V1+V2 \)) in M³.
\( P1 \) = Initial pressure at receiver in Kg/cm².
\( P2 \) = Final pressure at receiver in Kg/cm².
\( Pa \) = Atmospheric pressure in Kg/cm².
\( T \) = Cutoff time in minute for compressed air pressure (0 to 10 Kg/cm²).
\( Cc \) = Capacity of compressor.
\( \eta \) = Efficiency of compressor.
\( Dc \) = Design /Rated capacity of air compressor.

2. Precautions:
2.1. Air Compressor should be in OFF condition before carrying out the test.
2.2. Ensure that isolation valves of receiver are properly closed.
Example:
Below is the example of the performance assessment of Air Compressor of 600 CFM @ 10 bar capacity.

**Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>3.43 min</td>
</tr>
<tr>
<td>V1</td>
<td>5 m³</td>
</tr>
<tr>
<td>V2</td>
<td>0.11 m³</td>
</tr>
<tr>
<td>V</td>
<td>(V1+V2)</td>
</tr>
<tr>
<td>P1</td>
<td>0 kg/cm²</td>
</tr>
<tr>
<td>P2</td>
<td>10 kg/cm²</td>
</tr>
<tr>
<td>Pa</td>
<td>1.03 kg/cm²</td>
</tr>
<tr>
<td>Dc</td>
<td>600 CFM</td>
</tr>
</tbody>
</table>

Capacity calculation of Air Compressor as per formula,

\[ Cc = \frac{V(P2 - P1)/Pa \times T}{(V1 + V2)} \]

\[ = \frac{(5.11 \times 10)/ (1.03 \times 3.43)}{5.11} \text{ m}^3/\text{min} \]

\[ = 14.46 \text{ m}^3/\text{min} \]

\[ = 510.29 \text{ CFM (To convert m}^3/\text{min into CFM multiply by 35.28)} \]

To find out efficiency of Air Compressor

\[ \eta = \frac{Cc \times 100}{Dc} \]

\[ \eta = \frac{510.29 \times 100}{600} \]

\[ \eta = 85.05 \]

**Result**: The efficiency of air compressor is found 85%.
APPENDIX I

PERFORMANCE ASSESSMENT OF CHILLER

1. Procedure:
1.1 Ensure the condenser flow rate & Evaporator flow rate is as per design flow rate particular chiller in Liters per Hour. Flow rate can be measured with inline flow meter if available or with ultrasonic flow meter. If the flow meter is not available, flow can be calculated from the pump curve data.
1.2 Also ensure that the chiller is running at least 95% load.
1.3 Check chilled water return and leaving temperature. Note down the temperature in °C.
1.4 Calculate Difference in Temperature in °C, i.e. ΔT = T1 - T2.
1.5 The heat removed from the chilled water is equal to the product of the chilled water flow rate, the water temperature difference, and the specific heat of the water. Calculate Tons of Refrigeration of Chiller by using following formulae:

\[ TR = \frac{m \times cp \times \Delta T}{3024} \]

Where,
\[ M = \text{Mass flow rate across the Evaporator in liters/hrs.} \]
\[ Cp = \text{Specific Heat of water} \]
\[ T1 = \text{Return chilled water temperature in °C} \]
\[ T2 = \text{Leaving chilled water temperature in °C} \]
\[ \Delta T = \text{Difference in return and leaving temperature in °C} \]
\[ TR = \text{Tons of Refrigeration} \]

1.6 Calculate Power in KW by following formula:
a. Check current readings of chiller compressor motor and note down the same readings, i.e. R, Y, B phase current in Ampere
b. Note incoming voltage on chiller panel in Volts
c. Calculate average of current readings,
\[ I = \frac{R+Y+B}{3} \]

d. Calculate Power in KW by using formula:

\[ P = \frac{\sqrt{3} \times V \times I \times \cos \phi}{1000} \]

Where, 
- \( V \) = Voltage in volts
- \( I \) = Average Current in ampere
- \( P \) = Power in KW

1.7 Calculate Co-efficient of Performance (COP) of Chiller by using formula:

\[ \text{COP} = \frac{3.516}{\text{KW/ton}} \]

Example:

Sample Chiller Design Data:

Input Power = 324 KW, Output TR = 500 TR, KW/TR Ratio = 324/500 = 0.64.

Designed COP of Chiller by using formula:

(Please Note: 1 KW = 3.516 TR.)

\[ \text{COP} = \frac{3.516}{\text{KW/ton}} = \frac{3.516}{0.64} = 5.42 \]
<table>
<thead>
<tr>
<th>SR.NO</th>
<th>DETAILS</th>
<th>OBSERVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mass flow rate cross Evaporator (m)</td>
<td>m = 1340 (GPM) ×3.784 ×60 3,04,233 Liters/Hr.</td>
</tr>
<tr>
<td>2</td>
<td>Specific heat of water (Cp)</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Return chilled water temperature (T1)</td>
<td>10.2 ° C</td>
</tr>
<tr>
<td>4</td>
<td>Leaving chilled water temperature(T2)</td>
<td>5.5° C</td>
</tr>
<tr>
<td>5</td>
<td>Difference in Return and leaving temp. ΔT=T1-T2</td>
<td>4.7 ° C</td>
</tr>
<tr>
<td>6</td>
<td>Ton of refrigeration</td>
<td>TR = m ×Cp× ΔT/3024 472.84</td>
</tr>
<tr>
<td>7</td>
<td>Current across Red cable(R)</td>
<td>455</td>
</tr>
<tr>
<td></td>
<td>Current across Yellow cable(Y)</td>
<td>449</td>
</tr>
<tr>
<td></td>
<td>Current across Blue cable(B)</td>
<td>448</td>
</tr>
<tr>
<td>8</td>
<td>Average Current I=R+Y+B/3</td>
<td>451 Amps</td>
</tr>
<tr>
<td>9</td>
<td>Average Voltage (V)</td>
<td>415 Volts</td>
</tr>
<tr>
<td>10</td>
<td>Power factor (COS Ø)</td>
<td>0.98</td>
</tr>
<tr>
<td>11</td>
<td>Kilo watts Kw= √3 × V×I×COSØ/1000</td>
<td>317 KW</td>
</tr>
<tr>
<td>12</td>
<td>Kilo watts per Ton (Kw /Ton)</td>
<td>0.68</td>
</tr>
<tr>
<td>13</td>
<td>Coefficient of Performance of Chiller No. 01 COP=3.516</td>
<td>5.17</td>
</tr>
<tr>
<td></td>
<td>KW/ton</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Efficiency of chiller</td>
<td>= Actual COP × 100 = 5.17 × 100 [\text{Designed COP} = 5.42] 95.39 %</td>
</tr>
</tbody>
</table>
PERFORMANCE ASSESSMENT OF COOLING TOWER

1. Procedure:
1.1 Measure cooling tower inlet water temperature with calibrated thermometer in °C.
1.2 Measure cooling tower outlet water temperature with calibrated thermometer in °C.
1.3 Measure water flow rate across the cooling tower with ultrasonic water flow meter in Liters per Hour. If the flow meter is not available, the flow can be derived from pump curve.
1.4 Measure Intake air Wet Bulb Temperature and Dry Bulb Temperature at ground level using a whirling pyschrometer.
1.5 Measure exhaust air velocity in meter/second at the outlet of cooling tower fan with anemometer. Take the readings at last at four locations and calculate the average of the same.
1.6 Measure area of the fan in M².
1.7 Measure Total Dissolved Solids with TDS meter in PPM (parts per millennium) in both make up water and recirculating water.
1.8 Calculate the following parameters using the corresponding formulas.

a. Actual Fan CFM = Area*Avg. velocity
b. Volumetric Efficiency = \( \frac{\text{Actual Fan CFM}}{\text{Design CFM}} \times 100 \)
c. Actual TR = \( m \times c_p \times (T_{\text{in}} - T_{\text{out}}) \)
\[ 3024 \]
d. Cooling Tower Effectiveness = Range/(Range + Approach)*100
e. Evaporation loss in CMH = \( \text{Circulation Rate CMH} \times \text{difference in Temp. in °C} \)
\[ 675 \]
f. Cycles of Concentration = \( \frac{\text{Total Dissolved solids in makeup water}}{\text{Total dissolved solids in n recirculating water}} \)
g. Blow down losses = \( \frac{\text{Evaporation losses}}{\text{(COC -1)}} \)
Example:
The following is the data collected from a Cooling Tower,

**Design Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet water Temperature</td>
<td>34.444 °C</td>
</tr>
<tr>
<td>Outlet water Temperature</td>
<td>28.889 °C</td>
</tr>
<tr>
<td>Wet bulb Temperature</td>
<td>25.556 °C</td>
</tr>
<tr>
<td>Flow</td>
<td>536 M³/Hour</td>
</tr>
<tr>
<td>Design Approach</td>
<td>3.333°C</td>
</tr>
<tr>
<td>Design Range</td>
<td>5.55 °C</td>
</tr>
<tr>
<td>Design TR of CT</td>
<td>1163 TR</td>
</tr>
<tr>
<td>Design CFM of CT Fan</td>
<td>2,90,900 Cubic Feet/Minute (CFM)</td>
</tr>
<tr>
<td>Design Effectiveness</td>
<td>60.52%</td>
</tr>
<tr>
<td>Cooling Tower Fan Diameter</td>
<td>3.6576 Meter</td>
</tr>
<tr>
<td>Total Dissolved Solids (Make up water)</td>
<td>160 PPM</td>
</tr>
<tr>
<td>Total Dissolved Solids (Recirculating water)</td>
<td>500 PPM</td>
</tr>
</tbody>
</table>

**Actual Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature</td>
<td>26.6°C</td>
</tr>
<tr>
<td>Outlet Temperature</td>
<td>22°C</td>
</tr>
<tr>
<td>Delta Temperature (Range)</td>
<td>4.6</td>
</tr>
<tr>
<td>Dry Bulb Temperature</td>
<td>25.5°C</td>
</tr>
<tr>
<td>Wet Bulb Temperature</td>
<td>19°C</td>
</tr>
<tr>
<td>Frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Water Flow</td>
<td>610 Cubic Meter./Hour</td>
</tr>
<tr>
<td>Average air velocity</td>
<td>11.955 Meter/second</td>
</tr>
<tr>
<td>Area of the Fan</td>
<td>10.50 M².</td>
</tr>
</tbody>
</table>
Calculations:

a. Cooling Tower Approach = \([CW \text{ outlet temp (°C)} - \text{Wet bulb temp (°C)}]\) = 3°C

b. Actual Fan CFM = Area*Avg. velocity
   \[= \pi/4*(3.6576^2)*10.50\]
   \[= 22607.36\times 11.95\]
   \[= 265,606 \text{ CFM}\]

c. Volumetric Efficiency = \(\frac{\text{Actual Fan CFM}}{\text{Design CFM}}\)
   \[= \frac{265606}{290900}\times 100\]
   \[= 91.30\%\]

d. Actual Tons of Refrigeration = \(m \times cp \times (T_{in} - T_{out})\)
   \[= \frac{610 \times 1000 \times 4.6}{3024}\]
   \[= 927.91 \text{ TR}\]

e. Calculated Cooling Tower Effectiveness = \(\frac{\text{Range}}{(\text{Range + Approach})}\times 100\)
   \[= \frac{4.6}{4.6 + 3}\times 100\]
   \[= 60.25\%\]

f. Evaporation loss in M³/Hour = \(\frac{\text{Circulation Rate M³/Hour \times difference in Temp. In °C}}{675}\)
   \[= \frac{610 \times 4.6}{675}\]
   \[= 4.15 \text{ M³/Hour (0.68 % of circulation rate)}\]

g. Cycles of Concentration (COC) = \(\frac{\text{Total Dissolved Solids in Recirculating Water}}{\text{Total Dissolved Solids in Makeup Water}}\)
   \[= \frac{500 \text{ PPM}}{160 \text{ PPM}} = 3.125\]
h. **Blow down losses** = Evaporation loss (COC-1)  
\[ = \frac{4.15}{(3.125-1)} \]
\[ = 1.95 \text{ M}^3/\text{Hour} (0.32\% \text{ of circulation rate}) \]

i. **Make up water requirement** = Blow down losses + Evaporation Losses  
\[ = 1.95 \text{ M}^3/\text{Hour} + 4.15 \text{ M}^3/\text{Hour} \]
\[ = 6.1 \text{ M}^3/\text{Hour} (1 \% \text{ of Recirculation rate}) \]
PERFORMANCE ASSESSMENT OF CENTRIFUGAL PUMP

1.1 Measure flow of the pump with Ultrasonic Flow meter in M³/Hour. If the flow meter is not available, then calculate the flow from the pump curve.

1.2 Measure Head of the pump with the following formulae, in Meters,
Head = (Discharge Head – Suction Head)

1.3 Measure current drawn by the pump motor with current meter, Ampere.

1.4 Measure supply voltage with voltmeter, in Volts.

1.5 Note down the motor efficiency.

1.6 Note down the power factor of the motor.

1.7 Calculate power drawn by the motor by formulae,
Power drawn by motor = \(\sqrt[3]{V*I*\text{Power Factor}}\)

1.8 Calculate hydraulic power by formulae,
Hydraulic power = Q (M³/Second) x total head (Meter) x 1000 x 9.81 /1000

1.9 Calculate power input to the pump motor by formulae,
Power input to pump = Power drawn by motor * motor efficiency

1.10 Calculate the pump efficiency by formulae,
Pump efficiency = (Hydraulic power / Power input to pump) * 100

Example

Collected Data of a centrifugal Pump,
Flow: 624.930 (Flow Measured with Ultrasonic Flow meter)
Total head: 22 meters (Suction Pressure 0.4 Kg/cm² & Discharge Pressure 2.6 Kg/cm²),
Voltage= 395.5 Volts
Current= 89.36 Ampere
Power factor (motor) = 0.857
Motor efficiency = 95%.
Frequency = 50 Hz
Calculations:

a. **Power drawn by motor** = $\sqrt{3} \cdot V \cdot I \cdot \text{Power Factor}$

\[
= \frac{1.73 \times 395.5 \times 89.36 \times 0.857}{1000}
\]

\[= 52.39 \text{ Kw}\]

b. **Hydraulic power** = $Q \ (\text{M}^3/\text{Second}) \times \text{total head (Meter)} \times 1000 \times 9.81 / 1000$

\[
= \left(\frac{624.930}{3600}\right) \times 22 \times 1000 \times 9.81 / 1000
\]

\[= 37.46 \text{ Kw}\]

c. **Power input to pump** = Power drawn by motor $\times$ motor efficiency

\[= 52.39 \times 0.95\]

\[= 49.77 \text{ Kw}\]

d. **Pump efficiency** = (Hydraulic power / Power input to pump) $\times$ 100

\[= \left(\frac{37.46}{49.77}\right) \times 100\]

\[= 75.26\%\]

### Design Data of the pump under study

<table>
<thead>
<tr>
<th>Hydraulic power</th>
<th>37.46 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power input to pump</td>
<td>49.77 kW</td>
</tr>
<tr>
<td>Pump efficiency</td>
<td>75.26 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow:</th>
<th>535.6 M³/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head:</td>
<td>28.6 Meter</td>
</tr>
<tr>
<td>Power/ Speed</td>
<td>55 KW / 1485 RPM</td>
</tr>
</tbody>
</table>
COMPRESSED AIR GENERATION COST

Air Compressor is a machine that increases the pressure of air. To find cost of per m³ of compressed air, the cost of the following things are required to be considered necessarily.

1. Compressor motor power consumption
2. Cooling tower fan power consumption
3. Cooling Tower Pump power consumption
4. Compressed air Drier power consumption
5. Cooling tower make up water cost
6. Cooling tower water treatment cost
7. Manpower cost
8. Maintenance and Spares cost

Example:

Cost is calculated on the basis of compressor working for 24 hours

Cost of one unit of electricity is considered Rupees 9 /-

Cost of water/M³ - Rupees 10/-

Capacity of the air compressor – 600 CFM

Note: Manpower, spares & maintenance, housekeeping, water chemical treatment cost was calculated for one year and then calculated for 24 Hrs. (For Study period)

1. Compressor cooling water pump power consumption = 5 Kw x 24Hrs
   = 120 Kwh
   Cost of energy consumption = 120 x Rs.9
   = Rs. 1080/-

2. Cooling tower fan power consumption = 8 Kw X 24 Hrs.
   = 192 Kwh
   Cost of energy consumption = Rs. 1728/-
3. Compressor air Drier power consumption = 6.5 Kw X 24 Hrs.
   = 156 kW X Rs. 9/-

   Cost of energy consumption = **1404/-**

4. Cooling Tower make up water for 1 No. of cooling tower = **Rs. 150/-**

5. Cooling Tower Water treatment cost for 1 no. of cooling tower = **Rs. 360/-**

6. Manpower cost = **Rs.1250/-**

7. Maintenance and spares cost = **Rs. 1176/-**

8. Total Power consumption for 24 Hrs. = 2962 Kwh

   Cost of total energy consumption = 2962 X Rs.9

   = **Rs.26658/-**

9. Total Compressed air Generated in 24 Hrs. = **17761 M³**

10. Total cost to generate above quantity of compressed air = **Rs.33806/-**

11. Cost of 1 M³ of Compressed Air = **Rs.33806/-**

    = **Rs. 1.90 / M³**
CHILLED WATER GENERATION COST

Water is chilled by means of refrigeration in water chiller. Chiller circuit consists of chilled water system and condenser water system.

To find cost of per m³ of Chilled Water in an industry, the cost of the following things are required to be considered necessarily.

The study can be conducted for 7.5 hours also. To generate the chilled water, the following utilities /accessories are utilized. Power consumption readings are required to be taken of required accessories. Make up water cost, water chemical treatment cost, manpower cost, spares and maintenance cost are also required to be considered.

Note: Manpower, spares & maintenance, housekeeping, water chemical treatment cost was calculated for one year and then calculated for 7.5 Hrs. (For Study period).

Cost of one unit of electricity is considered Rs. 9 /-

1) Condenser water pump 4 nos.: = 28 Kwh X 4 Nos
= 112 Kwh
Cost of energy consumption = 112 X Rs.9/- X 7.5 Hrs.
= Rs. 7560/-

2) Primary water Pumps (3 Nos) = 30 Kwh X 3 Nos.
= 90 kwh
Cost of energy consumption = 90 X Rs.9/- X 7.5 Hrs.
= Rs. 6075/-
3) Cooling tower Fan (3 Nos) = 8 Kwh X 3 Nos
= 24 Kwh
Cost of energy consumption = 24 X Rs.9/- X 7.5 Hrs
= Rs. 1620/-

4) Chiller No. 01 = 250 Kwh
Cost of energy consumption = 250 X Rs.9/- X 7.5 Hrs.
= Rs. 16875/-

5) Chiller No. 02 = 247 Kwh
Cost of energy consumption = 247 X Rs.9/- X 7.5 Hrs.
= Rs. 16672/-

6) Chiller No. 03 = 250 Kwh
Cost of energy consumption = 250 X Rs.9/- X 7.5 Hrs.
= Rs. 16875/-

7) Cooling tower Make up water = Rs. 1751/-

8) Cooling tower water chemical cost = Rs. 552/-

9) Manpower cost = Rs. 949/-

10) Maintenance and spares cost = Rs. 505/-

11) Total chilled water generated = 4940 M³

12) Total cost = Rs.69434/-
13) Cost of 1 m³ of chilled water = Rs. 69434/-

COST OF CHILLED WATER = Rs.14/ M³
HOT WATER GENERATION COST

To find cost of per m³ of Hot Water in an industry, the cost of the following things are required to be considered necessarily.

1. Hot water circulation pump motor power consumption
2. Feed water pump motor power consumption
3. Burner blower motor power consumption
4. Fuel Gas consumption
5. Hot Water Generator shunt water pump motor power consumption
6. Softener Water consumption
7. Softener regeneration
8. Nitrogen cylinder consumption
9. Phosphate dosing cost
10. Sulphate dosing cost
11. PH Booster cost
12. Hot water Generator Operator cost
13. Manpower Cost

Example:
Cost is calculated on the basis of Hot Water Generator working for 24 hours
Cost of one unit of electricity is considered Rupees 9/-
Cost of water/M³ - Rupees 28/-
Capacity of Hot Water Generator 3.5 MW.
Note: Spares & maintenance, water chemical treatment cost was calculated for one year and then calculated for 24 Hrs. (For Study period)

a. Hot water circulation pump power consumption = 18 Kw * 24 Hours * Rs. 9 = Rs.3888/-
b. Feed pump power consumption = 1.44 Kw x 24 Hours * Rs. 9 = Rs.311.04/-
c. Burner blower motor power consumption = 8.6 Kw x 9 Hours * Rs.9 = Rs.696.6/-
d. Shunt pump power consumption = 0.7kw x 1/6 Hours * Rs.9 = Rs.1.05/-
e. Average Gas consumption for the day = 242M³ x Rs.59.987 = Rs. **14516.85/-**
f. Industrial water consumption per day = 0.253M³ x Rs.15.83 = Rs **7.084/-**
g. Regeneration cost of the softener = Rs **1.75/-**
h. Nitrogen cylinders consumption = Rs **23.33/-**
i. Phosphate dosing cost = Rs **1.57/-**
j. Sulphate dosing cost = Rs **1.41/-**
k. PH Booster cost per hour = Rs **1.75/-**
l. Operator Cost = Rs. 250 x 3 = Rs. **750/-**
m. Engineer Cost = Rs.200x3= Rs.**600/-**
n. Maintenance and spares cost = Rs.1141/-
o. Total Cost of Hot water generation = Rs.21941.434/-
p. Total circulation of Hot water generation/day = 1280 M³
q. Unit cost of Hot water generation = Rs.**17.14 /M³**
INDUSTRIAL WATER COST

To find cost of per m³ of Industrial Water in an industry, the cost of the following things are required to be considered necessarily.

1. Raw Water pump motor power consumption
2. Supply Water pump motor power consumption
3. Back wash water consumption
4. Operator cost
5. Engineer Cost
6. Water treatment cost if any
7. Maintenance and Spares cost

Example:

Cost is calculated on the basis of Pump House working for 24 hours

Cost of one unit of electricity is considered Rupees 9/-

Cost of water/M³ - Rupees 28/-

a. Raw water pump consumption = 20.64 kW x 12 Hrs. x Rs.9 = Rs.2229.12/-

b. Hydrometric pump power consumption = 10.5KW x 24 Hrs. x Rs.9 = Rs.2268/-

c. Back Wash water cost = 75 M³ x 2 times 2 sand filter*30 minutes Rs.28 = Rs.4200/-

d. Per day industrial water consumption = 1430 M³

e. Raw water cost = Rs. 1430 x 28 = Rs. 40400/-

f. Operator Cost = Rs.250 X 3 Shift = Rs 750/-

g. Engineer Cost = Rs.200 X 3 Shift= Rs. 600/-

h. Maintenance and Spares cost = Rs.500/-

i. Total Cost of industrial water generation = Rs.50587.12/-

j. Unit cost of Industrial water generation= Rs.50587.12/ 1430M³

k. Unit cost of Industrial water generation = Rs.35.37 /M³