Mitigation Enabling Energy Transition in the MEDiterranean region

Electrical Energy Management

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Energy Audits in Industrial Small Medium Enterprises (SMES) - Training Course

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Electrical Systems

- Electric Motors and Drives.
- Electric Fans.
- Electric Pumps.
- Compressed Air Systems.
- Lighting Systems.
Energy Basics Knowledge

- Energy Units and Formulas of calculations.
- Energy Balance.

Diagram:
- Facility
- Electricity 2,597,700 kWh
- Natural Gas 329,863 GJ
- Lighting 130,560 kWh
- Motors 1,516,619 kWh
- Compressors 116,379 kWh
- HVAC 34,286 kWh
- Chillers 274,560 kWh
- Miscellaneous 260,000 kWh
- Boiler 329,863 GJ
- Electric Heaters 100,100 kWh
Electrical Basics

• Electric Power Circuits;
  – DC Power (no reactive power is present)
    • Power (Watt) = Voltage (Volt) X Current (Ampere)
  – AC Power, Single Phase
    • Active Power (Watt) = Voltage (V) X Current (A) X Power Factor (Pf)
    • Reactive Power (VAr) = Voltage (V) X Current (A) X Sin Ø
    • Apparent Power (VA) = Voltage (V) X Current (A)
  – AC Power, Three Phase
    • Active Power (Watt) = √3 X Voltage (V) X Current (A) X Power Factor (Pf)
    • Reactive Power (VAr) = √3 X Voltage (V) X Current (A) X Sin Ø
    • Apparent Power (VA) = √3 X Voltage (V) X Current (A)

Cos Ø = Power Factor (PF)

Cos Φ = Power Factor (PF)
Electrical Basics

• Electrical Loads Type:
  – Resistive Load of Unity Power Factor.
  – Inductive Load of Lagging Power Factor.
  – Capacitive Load of Leading Power Factor.

• Power Factor:
  – Poor Power Factor is due to inductive loads and should be corrected in order to reduce the phase shift angle (Ø).
  – Power Factor correction could save energy upstream the location of power factor correction equipment and it improves the power quality because of reducing the reactive power demand in Power System.
  • Fg
• **Power Factor Correction**
  - **Benefits:**
    - Increase electrical distribution system capacity
    - Reduce utility charges
    - Reduce losses in transformers and feeders
  - **Methods:**
    - Source Correction: Capacitor is installed at the individual load or integrated into the equipment
    - Group correction: Capacitor is installed at a distribution transformer that feeds several loads
Motors and Drives

- Motors consume 55–65% of the industrial sector’s electrical energy
Motors and Drives

• The motor efficiency is expressed in the division of the mechanical shaft power (Useful) over the input electrical energy.

\[ \eta = \frac{\text{Mechanical Shaft Power (kW)}}{\text{Input Energy (kW)}} \times 100 \]

• Motor Load Factor is defined as the ratio between the actual loading to the motor and the maximum installed motor load.

\[ \text{Load Factor (LF)} = \frac{\text{Actual Average Load of Motor}}{\text{Maximum Motor Loading}} \]
Energy Efficiency opportunities in Motors Applications

- High Efficient Motors.

\[ kW_{\text{saving}} = kW_{\text{rating}} \times \left( \frac{1}{\eta_{\text{old}}} - \frac{1}{\eta_{\text{new}}} \right) \]

- Motors Controls;
  - Process Control.
  - Variable Speed Drives (VSD).

<table>
<thead>
<tr>
<th>Efficiency of Electric Motors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>150 kW (200 HP)</td>
</tr>
<tr>
<td>75 kW (100 HP)</td>
</tr>
<tr>
<td>37,3 kW (50 HP)</td>
</tr>
<tr>
<td>18,7 kW (25 HP)</td>
</tr>
<tr>
<td>11,2 kW (15 HP)</td>
</tr>
<tr>
<td>7,5 kW (10 HP)</td>
</tr>
<tr>
<td>3,7 kW (5 HP)</td>
</tr>
<tr>
<td>1,5 kW (2 HP)</td>
</tr>
<tr>
<td>1,1 kW (1.5 HP)</td>
</tr>
<tr>
<td>0,7 kW (1 HP)</td>
</tr>
</tbody>
</table>

Affinity Law - Centrifugal

\[ \frac{LPS_{\text{new}}}{LPS_{\text{old}}} = \frac{RPM_{\text{new}}}{RPM_{\text{old}}} \]

\[ \frac{\text{Head}_{\text{new}}}{\text{Head}_{\text{old}}} = \left( \frac{RPM_{\text{new}}}{RPM_{\text{old}}} \right)^2 \]

\[ \frac{kW_{\text{new}}}{kW_{\text{old}}} = \left( \frac{RPM_{\text{new}}}{RPM_{\text{old}}} \right)^3 \]

**LPS**: Flow in liter per second.

**Head**: Discharge Head.

**kW**: Motor input power.

**RPM**: shaft speed in rotation per minute.

**kPa**: Kilo Pascal
Electric Fans

• With fans, four basic approaches for energy efficiency are feasible:
  – Reduction of hours of operation
  – Improve equipment efficiency
  – Flow reduction
  – Pressure reduction

The Same Affinity Laws are applied to fans very similar to pumps

\[
\text{Fan input power (Watt)} = \frac{LPS}{\text{Fan or Pump set Efficiency}} \times \text{Discharge Pressure (kPa)}
\]
Pumps/Fans Controls

• To Control the performance efficiency, the approach is:
  – Reduction of hours of operation
  – Equipment efficiency
  – Flow reduction
  – Pressure reduction

• To control the hours of operation, the strategy is:
  – Manual control
  – Timers
  – Centralized building controls
  – Start-stop set points
  – Occupancy sensors
Pump Operation and Design Consideration

**Pump Curve – Manufacturer Data Sheet**

- **Head (m)** vs. **Flow (l/s)**
- **Efficiency (%)** vs. **Flow (l/s)**
- **Power (kW)** vs. **Flow (l/s)**
- **Guarantee Point**

**System Curve – Analysis and Study**

- **Head (m)** vs. **Flow (l/s)**
- **Friction Losses α V^2**
- **Dynamic Head**
- **Static Head**
- **Useful Work**

**Pump Operating Point**

- **Head**
- **Friction Head**
- **Static Head**
- **Total Head**
- **Operating Point**
- **Flowrate**
Pump Flow Control Schemes

Flow control with throttling

- Pressure in kPa
- Volume in L/s
- Operation point valve limiting liquid flow
- $kW = f(\text{volume, pressure})$
- $kW = 0.6 \text{ volume} \times 1.4 \text{ pressure} = 0.84$

Flow control with VSD

- Pressure in kPa
- Volume in L/s
- Operation point reduced speed
- Operation point initial speed
- $kW = f(\text{volume, pressure})$
- $kW = 0.6 \text{ volume} \times 0.6 \text{ pressure} = 0.36 kW$
Compressed Air Systems

- Energy Efficiency Opportunities;
  - Reduction of air losses
  - Modification of distribution system
  - Modification of other systems
  - Compressor efficiency
  - Optimization of distribution pressure
  - Compressor control
  - Multi-stage compressors
Compressed Air Systems

- Potential Savings to Compressed Air Systems;
  - Leak reduction is a very cost-effective energy conservation measure.
  - The payback period is too short.

<table>
<thead>
<tr>
<th>Hole diameter (mm)</th>
<th>Air consumption at 6 bar (g)</th>
<th>m³/min</th>
<th>Loss kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.065</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>0.240</td>
<td></td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>0.980</td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>4</td>
<td>2.120</td>
<td></td>
<td>12.0</td>
</tr>
</tbody>
</table>
Compressed Air Systems

• Measures to consider;
  – Distribution system Modifications (if there are large pressure drops)
    • Pipe selection according to a pressure drop of 5% or less in initial pressure
    • Replace piping when the diameter is too small
    • Add new piping in parallel
    • Generously size filters, final coolers, air dryers and fittings
    • Replace fast fittings by fixed fittings for permanent tools
  – Compressor Efficiency;
    • Relocate inlet (colder air)
    • Replace standard motors with high-efficiency ones
    • Replace filters regularly: excessive pressure drop in filters also wastes energy
    • Choose the right air dryer; Desiccant or Refrigeration-based
Compressed Air Systems

- Measures to consider;
  - Multi Stage Compressors;
    - Two-stage flooded rotary screw compressors offer significant power savings over single-stage compressors.
    - Unless power is extremely inexpensive or the daily operational time is very short, two-stage compressors typically provide a return on the investment within the first two years of operation, and often within the first.
  - Air dryer optimization;
    - Air dryers can be a huge energy consumer.
    - The refrigeration type are usually good in terms of efficiency.
    - The absorption type used in the moisture-sensitive type should be carefully adjusted.
  - Venturi nozzles to reduce air flow;
Lighting Systems

- Lighting Systems Consumption Distribution;

![Global Energy Consumption of Lighting per Sector](image)

- Residential: 29%
- Commercial: 46%
- Industrial: 17%
- Outdoor lighting: 8%
Lighting Systems

- **Objectives:**
  - Discuss concepts and characteristics of energy-effective lighting design
  - Identify typical lighting energy conservation opportunities
  - Demonstrate lighting economics calculations and relationships

- **Quality:**
  - **Color Rendering Index (CRI)**
    - Indicates the effect on the color appearance of objects illuminated by the light source of a particular colour temperature
      - 90 – 100 CRI = Excellent color rendition
      - 75 - 85 CRI = Good color rendition
      - 55 – 70 CRI = Fair color rendition
      - 0 – 55 CRI = Poor color rendition.
  - **Correlated Color Temperature (CCT)**
    - The color appearance of light emitted from a light
      - < 3200 K = “warm” or red side of spectrum
      - > 4000 K = “cool” or blue side of spectrum
Lighting Systems – Definitions

- **Lumen**: measure unit of the total "amount" of visible light emitted by a source (symbol: lm)
- **Lux**: unit of illuminance and luminous emittance, measuring luminous flux per unit area; equals 1 lm/m². (symbol: lx)
- **Luminous efficacy**: measure of how well a light source produces visible light; it is the ratio of luminous flux to power in lm/W
- **Colour temperature**: of a light source: the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source
Typical Lighting Level

- Building area
- Office – general
- Auditorium
- Bathroom
- Dining room
- Conference room
- Corridors and stairs
- Local roads
- Highways

Lux
400
400
300
100
300
50
3 to 8
6 to 14
Lighting Source Technology

- Incandescent
- Halogen
- Metal halide
- Fluorescent
- Mercury vapour
- High-pressure sodium
- Induction
- LED
Typical Lifespan Of Various Light Source Technologies

- **Incandescent**: 750~1,000 hours
- **Halogen**: 2,000~3,000 hours
- **Metal Halide**: 7,500~10,000 hours
- **Fluorescent**: 15,000~20,000 hours
- **Mercury Vapor**: 16,000~24,000 hours
- **High Pressure Sodium**: 15,000~25,000 hours
- **High Power LEDs**: 45,000~55,000 hours
- **Internal Inductor Induction Lamps**: 60,000~75,000 hours
- **External Inductor Induction Lamps**: 85,000~100,000 hours
Efficacy of Light Source Technologies

<table>
<thead>
<tr>
<th>Light Source Technology</th>
<th>Lumens per Watt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>10-17</td>
</tr>
<tr>
<td>Halogen A-line</td>
<td>12-22</td>
</tr>
<tr>
<td>White LED</td>
<td>70-125</td>
</tr>
<tr>
<td>Mercury Vapour</td>
<td>70-115</td>
</tr>
<tr>
<td>Linear Fluorescent</td>
<td>50-140</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>50-140</td>
</tr>
<tr>
<td>High-Pressure Sodium</td>
<td>50-140</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>50-140</td>
</tr>
<tr>
<td>Induction</td>
<td>50-140</td>
</tr>
</tbody>
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