Mitigation Enabling Energy Transition in the MEDiterranean region

Thermal Energy Management

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

Monday, 9 December 2019 – Cairo, Egypt
Thermal Systems

- Energy Flows.
- Heat Transfer.
- Boilers and Steam Systems.
- Waste Heat Recovery.
- Automation Systems.
Energy Flows

- The energy flows defines the energy conversion, transformation, and transfer through energy balance diagram.
- This energy balance “business as usual” starts with the primary energy till the final consumed energy in a certain activity.
- Accordingly, on starting with primary energy the final energies can be in form of lighting source, mechanical power, electrical energy, chemical energy, heating process, cooling process, ……etc.
Energy Flows

• Energy Flow in Building
The Heat Flow

- The heat flow is processed through heat transfer that takes place by three modes;
  - Conduction (proportional to $\Delta t$)
  - Convection (approx. prop. to $\Delta t^2$)
  - Radiation (approx. prop. to $\Delta t^4$)

- Heat Transfer by Conduction;
  - Heat is lost and gained through the building shell.
Heat Flow Equation

- The heat flow equation is:

\[ Q(Watt) = U \times A \times \Delta T \]

Where:
Q: Heat Flow in Watt
U: Overall thermal conductance (Watt/m². °C).
A: Area (m²)
\( \Delta T \): Temperature Difference (°C)
Heat Flow Equation

• For Water

\[ Q(kW) = LPS \times 4.2 \times \Delta T \]

• For Air

\[ Q(Watt) = LPS \times 1.2 \times \Delta T \]

LPS: Flow rate in Liter per Second.
\( \Delta T \): Temperature Difference (°C).
HVAC System

- HVAC is to provide and maintain a comfortable environment within a specific space for the occupants or for process through the control of the following parameters:
  - Temperature
  - Humidity
  - Air Quality
  - Air Distribution
HVAC System Components

• **Primary Equipment;**
  – Chillers (Big)
  – Direct expansion (DX) systems (Rooftop, Pad Mount)
  – Boilers (Gas - Steam)
  – Cooling Towers

• **Secondary Side (Air Side)**
  – Fan coil system
  – Single duct, single zone system
  – Dual duct system
  – Single duct, variable air volume system
HVAC System Components

- CTWS
- CTWR
- Chiller
- Chiller
- Boiler
- Condensate Tank
- Steam
- Hot Water
- Load
- CHWS
- CHWR
- HWS
- HWR
- Condensate
HVAC Systems – Cooling Cycles

- Vapor Compression Cycle
  - Mechanically Driven.

- Absorption Cycle
  - Thermally Driven
Energy Balance of Cooling Cycle

\[ Q_{\text{input}} + Q_{\text{load}} - Q_{\text{rejected}} = 0.0 \]

\( Q_{\text{input}} \): Input Energy to Cycle – Work input or thermal input

\( Q_{\text{load}} \): Cooling Effect (Load) - Evaporator

\( Q_{\text{rejected}} \): Energy rejected from cycle through condenser.
Power and Energy Terms in HVAC

- Cooling Capacity is expressed in Tons of Refrigeration (TOR). TOR is 12,000 Btu/hr.
- 1 TOR = 12,000 Btu/hr = 3.517 kW
- HVAC Performance Measures:

\[
\begin{align*}
\text{EER} & = \frac{\text{BTU of Cooling output}}{\text{Wh of Electric input}} \\
\text{COP} & = \frac{\text{Energy Output}}{\text{Energy Input}} \\
\text{SEC} & = \frac{3.517}{\text{COP}} \frac{\text{KWe}}{\text{TOR}} \\
\text{SEC} & = \frac{12000}{\text{EER}} \frac{\text{KWe}}{\text{TOR}}
\end{align*}
\]

\[
\text{COP} = \frac{\text{EER}}{3412}
\]
HVAC Systems – Opportunities to Save Energy

• Investigate the chiller performance (COP).
• Chiller operation versus served load.
• Chiller Set point adjustment.
• Energy Management Controllers to Primary Equipment.
• Energy Management Controllers to Secondary Equipment.
Boilers and Steam Systems

- System Components:

![Diagram of a steam system](image-url)
Boilers and Steam Systems – Energy Savings Opportunities

• Combustion system improvement and controls.
• Flue Gas Energy Recovery.
• Blowdown Process Automation.
• Heat Recovery for Blowdown.
• Steam Traps Repair and improvement.
• Heat Transfer Surfaces improvement.
• Steam pipes insulation.
# Waste Heat Recovery Systems

## Waste Energy → Heat Recovery System (Heat Exchanger) → Useful Energy

<table>
<thead>
<tr>
<th>Waste Heat Sources</th>
<th>Uses for Waste Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Combustion Exhasts:</td>
<td>• Combustion air preheating</td>
</tr>
<tr>
<td>- Glass melting furnace</td>
<td>• Boiler feedwater preheating</td>
</tr>
<tr>
<td>- Cement kiln</td>
<td>• Load preheating</td>
</tr>
<tr>
<td>- Fume incinerator</td>
<td>• Power generation</td>
</tr>
<tr>
<td>- Aluminum reverberatory furnace</td>
<td>• Steam generation for use in:</td>
</tr>
<tr>
<td>- Boiler</td>
<td>- power generation</td>
</tr>
<tr>
<td>• Process off-gases:</td>
<td>- mechanical power</td>
</tr>
<tr>
<td>- Steel electric arc furnace</td>
<td>- process steam</td>
</tr>
<tr>
<td>- Aluminum reverberatory furnace</td>
<td>• Space heating</td>
</tr>
<tr>
<td>• Cooling water from:</td>
<td>• Water preheating</td>
</tr>
<tr>
<td>- Furnaces</td>
<td>• Transfer to liquid or gaseous process streams</td>
</tr>
<tr>
<td>- Air compressors</td>
<td></td>
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<tr>
<td>- Internal combustion engines</td>
<td></td>
</tr>
<tr>
<td>• Conductive, convective, and radiative losses from equipment:</td>
<td></td>
</tr>
<tr>
<td>- Hall-Héroult cells               ^a</td>
<td></td>
</tr>
<tr>
<td>• Conductive, convective, and radiative losses from heated products:</td>
<td></td>
</tr>
<tr>
<td>- Hot cokes</td>
<td></td>
</tr>
<tr>
<td>- Blast furnace slags               ^a</td>
<td></td>
</tr>
</tbody>
</table>

^a: Specific conditions or parameters may apply.
## Waste Heat Resources and Recovery Potential

<table>
<thead>
<tr>
<th>Temp Range</th>
<th>Example Sources</th>
<th>Temp (°F)</th>
<th>Temp (°C)</th>
<th>Advantages</th>
<th>Disadvantages/Barriers</th>
<th>Typical Recovery Methods/Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong> &gt;1,200°F (&gt;650°C)</td>
<td>Nickel refining furnace</td>
<td>2,500-3,000</td>
<td>1,370-1,650</td>
<td>High-quality energy available for a diverse range of end-uses with varying temperature requirements</td>
<td>High temperature creates increased thermal stresses on heat exchange materials</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td></td>
<td>Steel electric arc furnace</td>
<td>2,500-3,000</td>
<td>1,370-1,650</td>
<td>High-efficiency power generation</td>
<td>Increased chemical activity/corrosion</td>
<td>Steam generation for process heating or for mechanical/electrical work</td>
</tr>
<tr>
<td></td>
<td>Basic oxygen furnace</td>
<td>2,200</td>
<td>1,200</td>
<td>High heat transfer rate per unit area</td>
<td></td>
<td>Furnace load preheating</td>
</tr>
<tr>
<td></td>
<td>Aluminum reverberatory furnace</td>
<td>2,600-2,200</td>
<td>1,100-1,200</td>
<td></td>
<td></td>
<td>Transfer to mid-low temperature processes</td>
</tr>
<tr>
<td></td>
<td>Copper refining furnace</td>
<td>1,400-1,500</td>
<td>760-820</td>
<td></td>
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<tr>
<td></td>
<td>Steel heating furnace</td>
<td>1,700-1,900</td>
<td>930-1,640</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Copper reverberatory furnace</td>
<td>1,650-2,000</td>
<td>900-1,090</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen plants</td>
<td>1,200-1,800</td>
<td>650-950</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Furnace incinerators</td>
<td>1,200-2,600</td>
<td>650-1,430</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Glass melting furnace</td>
<td>2,400-2,800</td>
<td>1,300-1,540</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Coke oven</td>
<td>1,200-1,800</td>
<td>650-1,600</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Iron cupola</td>
<td>1,500-1,800</td>
<td>820-920</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium</strong> 450-1,200°F [230-650°C]</td>
<td>Steam boiler exhaust</td>
<td>450-900</td>
<td>230-480</td>
<td>More compatible with heat exchanger materials</td>
<td></td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td></td>
<td>Gas turbine exhaust</td>
<td>700-1,000</td>
<td>370-540</td>
<td></td>
<td></td>
<td>Steams followed by recovery for power generation</td>
</tr>
<tr>
<td></td>
<td>Reciprocating engine exhaust</td>
<td>600-1,100</td>
<td>320-590</td>
<td>Practical for power generation</td>
<td></td>
<td>Furnace load preheating, feedwater preheating, transfer to low-temperature processes</td>
</tr>
<tr>
<td></td>
<td>Heat treating furnace</td>
<td>800-1,200</td>
<td>430-650</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Drying &amp; baking ovens</td>
<td>450-1,100</td>
<td>230-590</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Cement kiln</td>
<td>840-1,150</td>
<td>450-620</td>
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</tr>
<tr>
<td><strong>Low</strong> &lt;450°F [&lt;230°C]</td>
<td>Exhaust gases exiting recovery devices in gas-fired boilers, ethylene furnaces, etc.</td>
<td>150-450</td>
<td>70-230</td>
<td>Large quantities of low-temperature heat contained in numerous product streams.</td>
<td>Few end uses for low temperature heat</td>
<td>Space heating</td>
</tr>
<tr>
<td></td>
<td>Process steam condensate</td>
<td>130-190</td>
<td>50-90</td>
<td></td>
<td>Low-efficiency power generation</td>
<td>Domestic water heating</td>
</tr>
<tr>
<td></td>
<td>Cooling water from:</td>
<td></td>
<td></td>
<td></td>
<td>For combustion exhausts, low-temperature heat recovery is impractical due to acidic condensation and heat exchanger corrosion</td>
<td>Upgrading via a heat pump to increase temp for end use</td>
</tr>
<tr>
<td></td>
<td>furnace doors</td>
<td>90-130</td>
<td>30-50</td>
<td></td>
<td>Organic Rankine cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>annealing furnaces</td>
<td>150-450</td>
<td>70-230</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>air compressors</td>
<td>80-120</td>
<td>30-50</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>internal combustion</td>
<td>150-250</td>
<td>70-120</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>engines</td>
<td>90-110</td>
<td>30-40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>air conditioning and refrigeration condensers</td>
<td>200-450</td>
<td>90-230</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drying, baking, and curing ovens</td>
<td>200-450</td>
<td>90-230</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hot processed liquids/solids</td>
<td>90-450</td>
<td>30-230</td>
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</tbody>
</table>
Control and Automation of Energy Systems

- Energy effective systems require energy effective controls (manual or automatic)

- Energy effective controls means that first we need to understand how the equipment SHOULD be operated and controlled, and then put such systems in place.

- Requires that the system is properly installed, operational and commissioned.
Types of Control

- **Manual Controls**
  - Switches
  - Dimmers
- **Basic Automatic Controls (Open Loop)**
  - Timers
  - Photo-sensors (to detect external darkness)
- **Basic Automatic Controls (Closed Loop)**
  - Thermostat
  - Humidistat
  - Dimmable ballast with photo sensor
Control Technologies

• Pneumatic control - compressed air powered controls
  – 20 - 100 kPa air systems
  – Typical of older systems or hazardous areas

• Electric control - voltage or current powered
  – 0 - 5 V, 0 - 10 V, 4 - 20 mA continuous
  – Typical of discrete control systems and some very old BMS

• Direct Digital Control - electronic
  – pulses; 0s and 1s; pulse coded data, discrete
  – interfaces directly with PCs, and the Internet
  – Should have interface with BacNet, LonWorks, etc and TCP/IP
Control System Hierarchy

- **Field Devices** (Sensors, Actuators, ...etc.)
  - **Inputs** (measured Values/feedback signals)
  - **Outputs** (Control Actions)

- **Input / Output Carrier Modules**

- **Data Processing and Control Algorithm (Controller)**
  - **Working Station**
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