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GE106:Introduction to Engineering Design

Concept Generation and Evaluation

By

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Introduction

So far you should know how to:

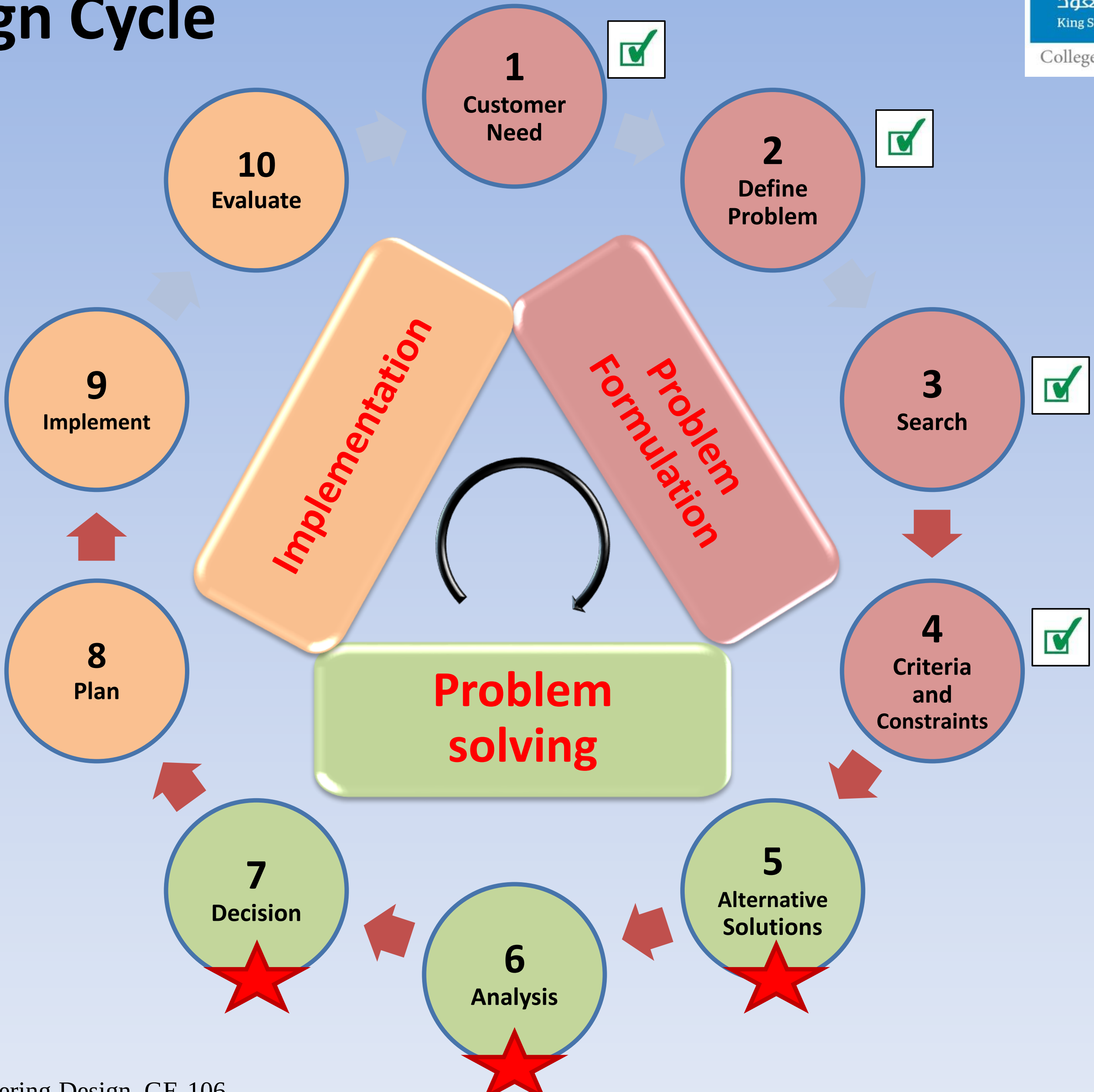
- Interpret the needs and analyze them
- Specify the objectives (both primary and secondary)
- Formulate the constraints and criteria
- Determine the human factors
- Conduct a morphological analysis and generate concepts.

Today you will learn how to:

- Evaluate alternatives through the **weight-and-rate** technique

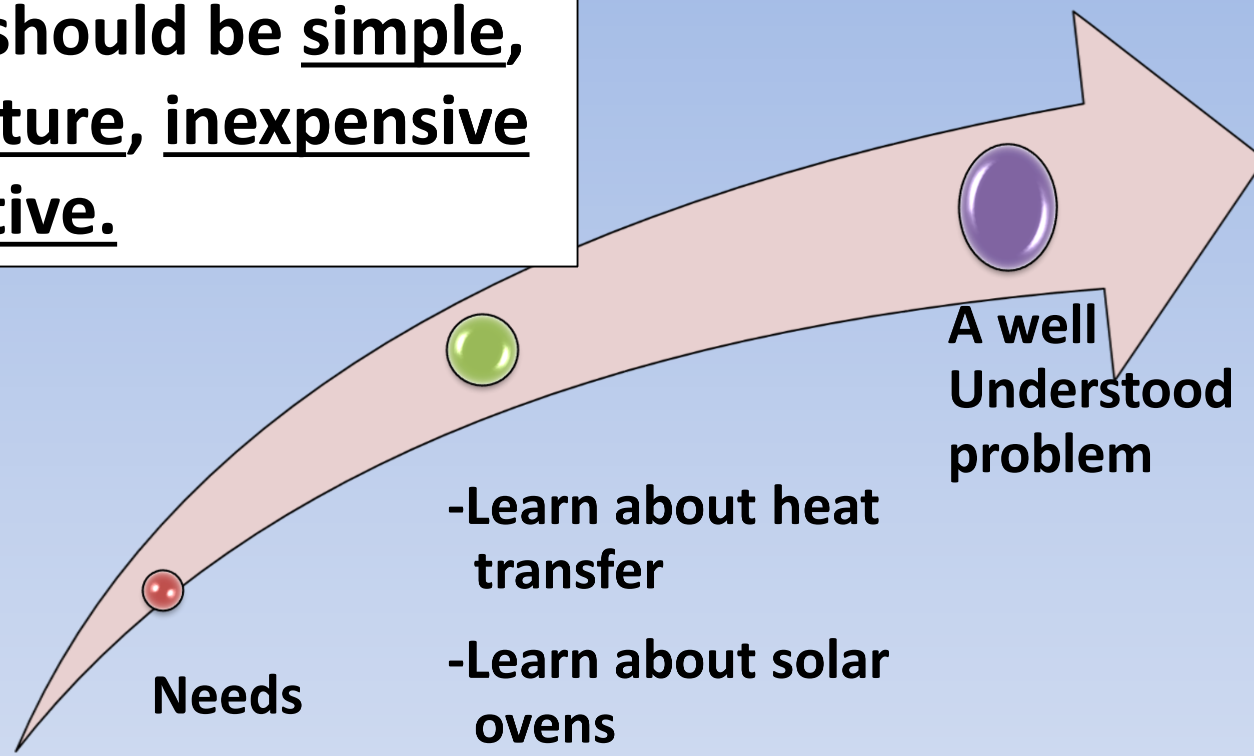
This will be covered through a "solar oven" design example.

The Design Cycle



The Solar Oven Example

It is required to design a solar oven. The oven should be simple, easy to manufacture, inexpensive and highly effective.



The first step is not about finding solutions; it is about understanding the problem.

Heat Transfer

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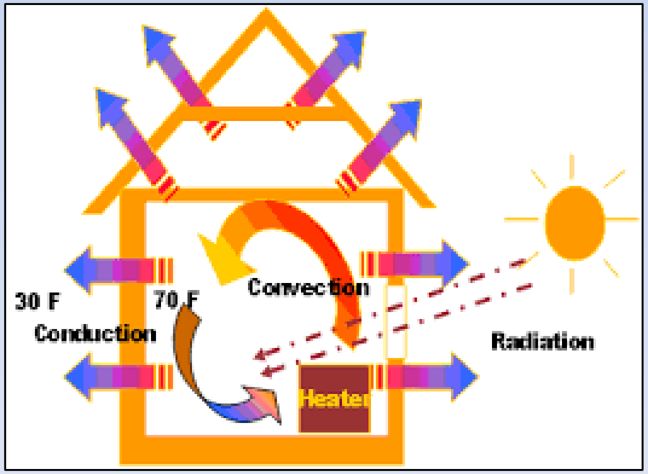
It occurs through one of three modes when a ΔT exists;

1. **Conduction:** Heat travels from atom to atom of a solid.
   Example: Metallic doorknob will be hot if fire is on the other side.

2. **Convection:** With a gas or liquid, the heat propagates as the molecules in the fluid move.
   Example: When you open the door of an oven, the temperature in the kitchen increases.

3. **Radiation**: A heated surface emits electromagnetic waves which carry energy away from the emitting object. This form does not require a medium, it can travel in a vacuum.
   Example: Heat felt from a brick wall that has been in the sun all day.



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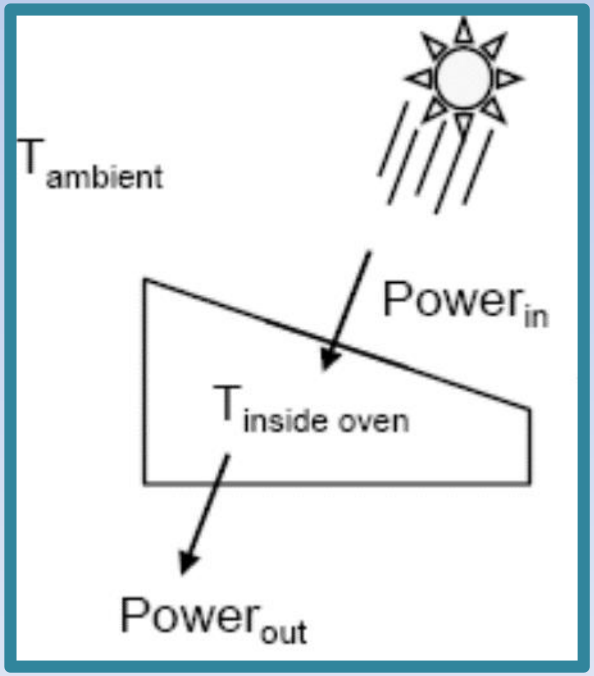
Understanding the Problem

$$\Delta T = T_{inside\ oven} - T_{ambient}$$



Criteria:
- **Maximize ΔT**
- **Minimize Cost**

Key Ideas

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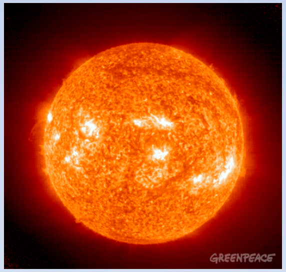
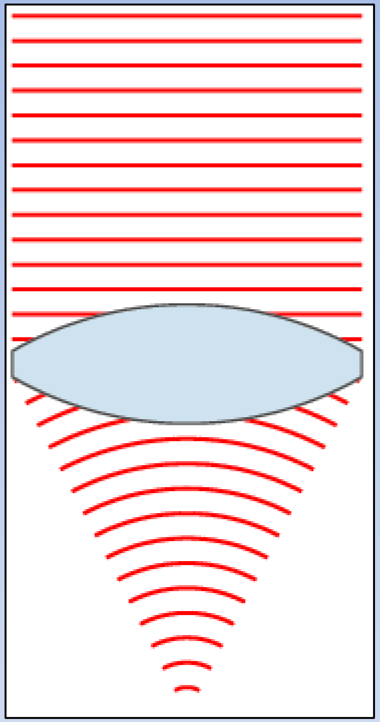
– Sunlight contains energy.
– You want your oven to receive solar energy easily.
– You want a solar oven that gets as hot as possible (highest temperature in oven chamber).
– You also want your oven not to loose the solar energy it has captured/received.



Needs (Specifications)

- Low Cost
- Maximum Temperature
- No lenses will be used in the design
- Size of chamber (partition)
- No preheating
- Presence of a thermometer
- High simplicity
- …



Solar Oven Heat Transfer

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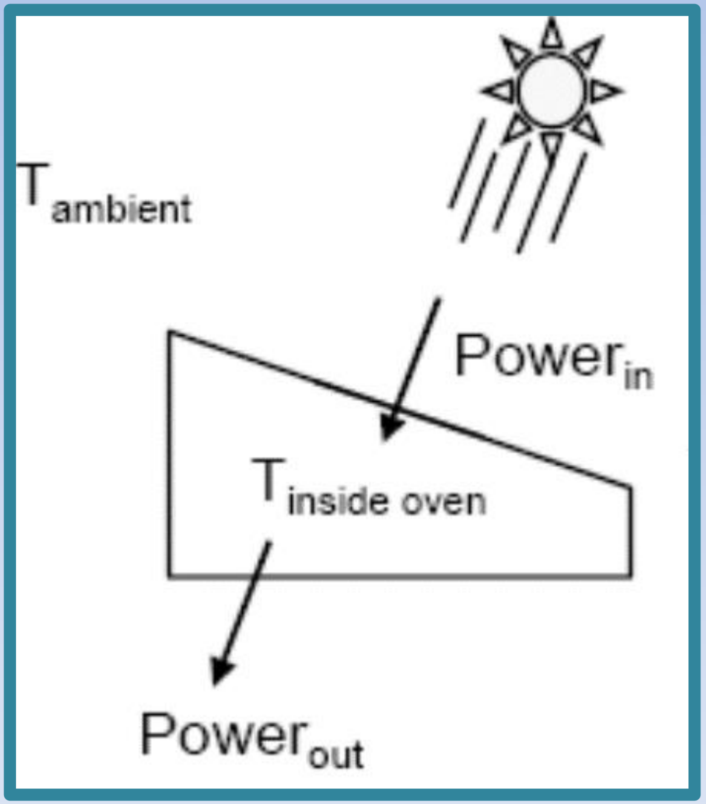
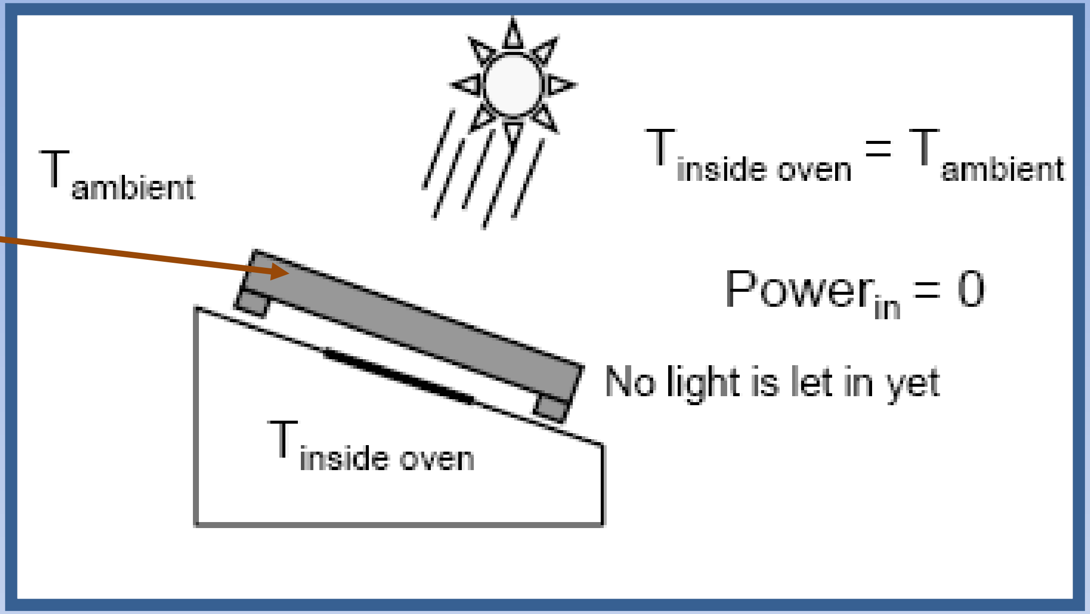
$$\Delta T = T_{inside\ oven} - T_{ambient}$$



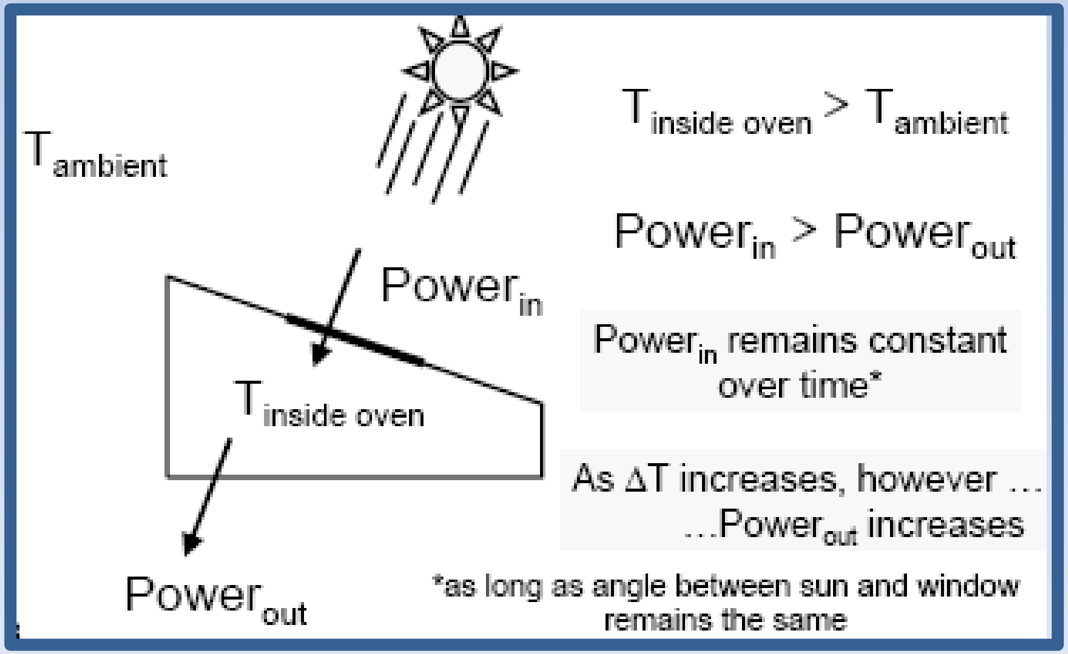
*Thermal **power** is how fast heat is produced. This is directly proportional to how fast the* $\boldsymbol{\Delta T}$ *increases.*

Time = 0

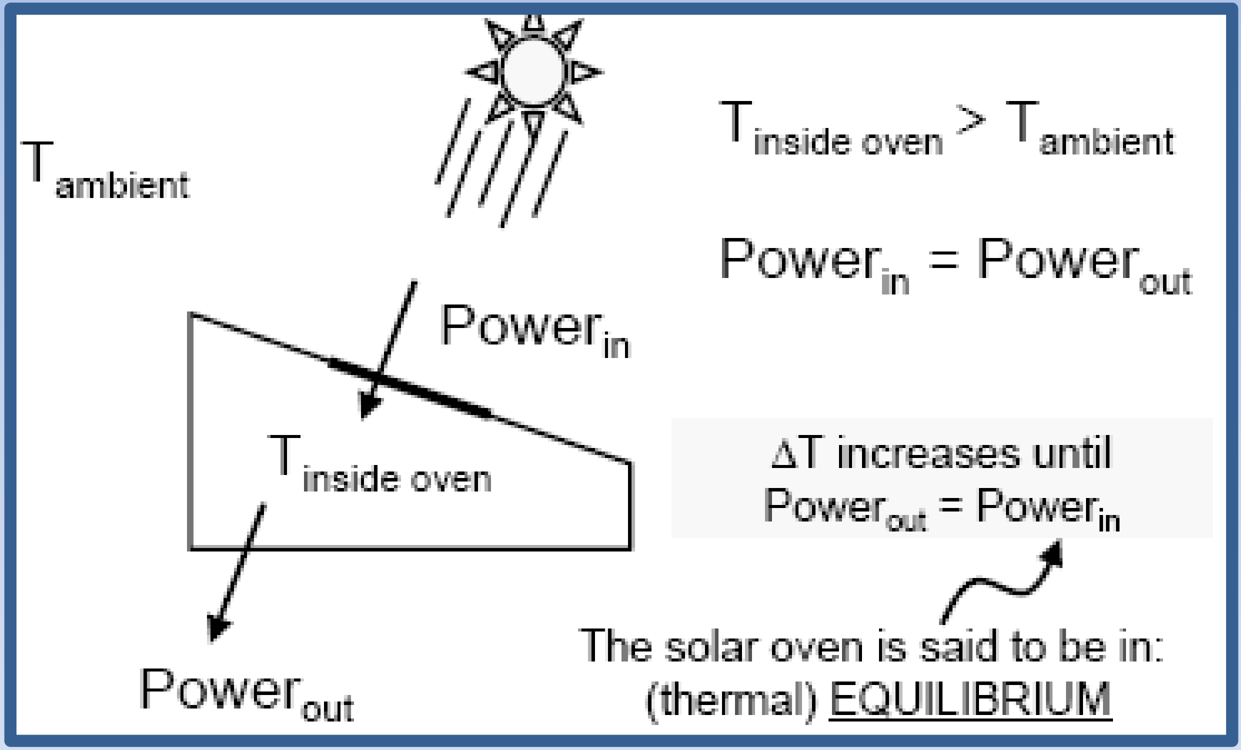
Cover



Time = Shortly after Cover is Removed



Time = a long time after "t=0"



Rate at which heat energy is generated inside the oven equals rate at which heat energy is being lost to the environment, this is thermal equilibrium.

Summarizing What We Know

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- We want the largest ΔT we can get for a given cost
- To get a larger ΔT, we need either to:
  1. Increase Power in (*get more sun into the oven*)
  2. Decrease Power out for a given ΔT (*reduce the rate at which energy is leaving the oven i.e. rate at which energy is lost to the surrounding*)

$$\uparrow \Delta T = \uparrow T_2 - T_1$$

OR

$$\uparrow \Delta T = T_2 - \downarrow T_1$$

How can Power be Increased? ↑ $Power_{in}$

Solar Intensity = 1,000 W/m^2

↓

Increase the area

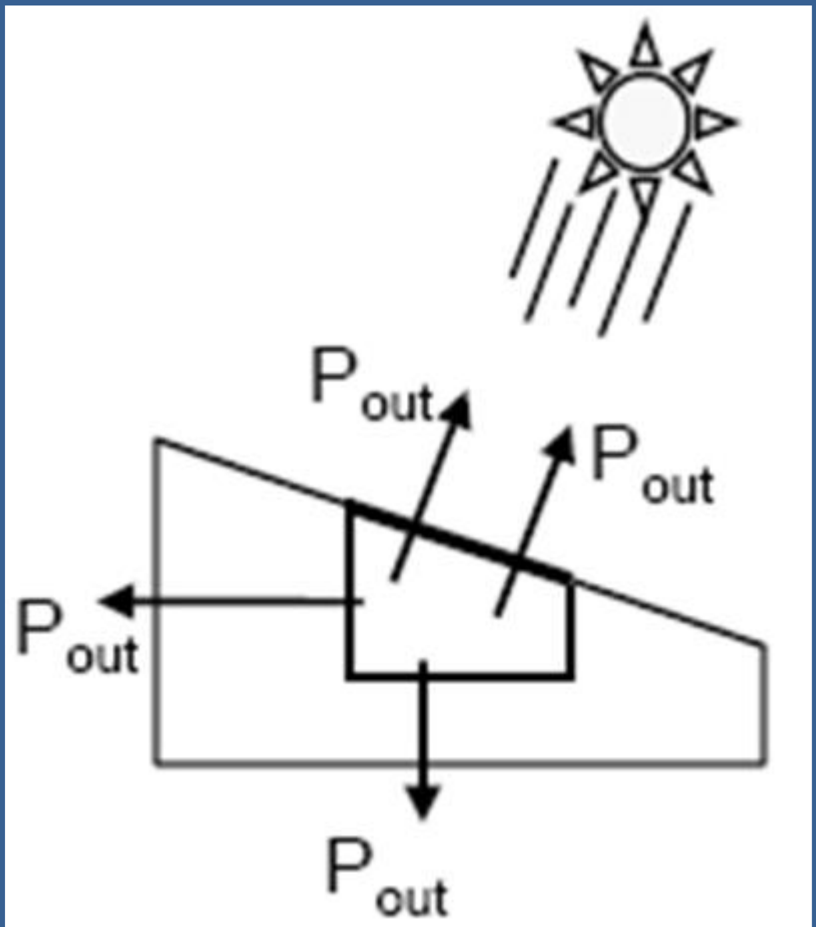
What determines $Power_{in}$:

- Window Size
- Intensity of the Sun
- Window Thickness
- Angle at which light hits window
- Color of oven Wall*

To increase $Power_{in}$:

- Bigger window area (increase area)
- Thinner window* (decrease thickness)

How can we decrease $Power_{out}$ for a given ΔT?



$Power_{out}$ measures how thermal energy is being lost to the surrounding.

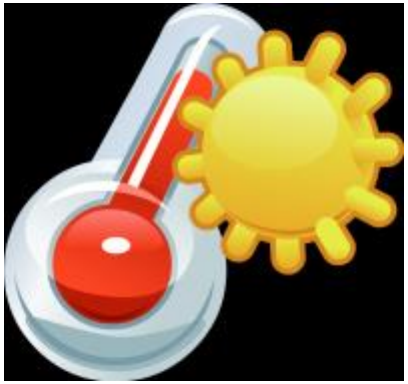
Energy leaves the oven through:

- **Radiation**
  (back out through the window)
- **Conduction and Convection**
  - **back out through window**
  - **sides of oven**
  - **bottom of oven**

Decreasing Power$_{out}$ for a given ΔT?

Heat Transfer via Oven's Window

- About 25 W /(m^2 °C) when T inside oven = 150°C
- About 12 W/(m^2 °C) for a thicker window



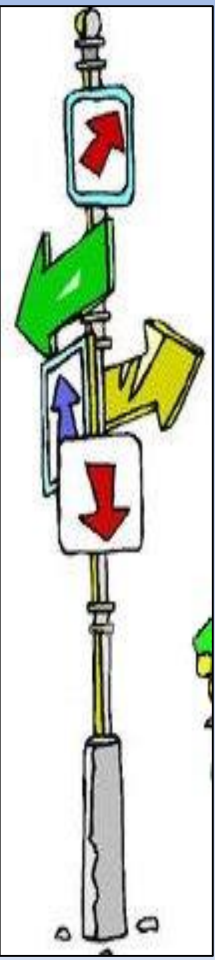
Heat Transfer via Sides and Bottom

- About 1.5 W/(m^2 °C)

More heat is lost through window

- Therefore, you want a smaller, thicker window to keep the heat energy in!
- Also, some good insulation on the sides and bottom

Putting it all Together



- To increase $Power_{in}$
  - Increase window size
  - Decrease window thickness

- To decrease $Power_{out}$
  – Decrease window size
  – Increase window thickness

- Conflicting objectives? well, this is Engineering Design; you must make tradeoffs (compromise)

Solar Oven Concept Generation (Brainstorming)

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No Reflector

Single Flat Reflector

Parabolic

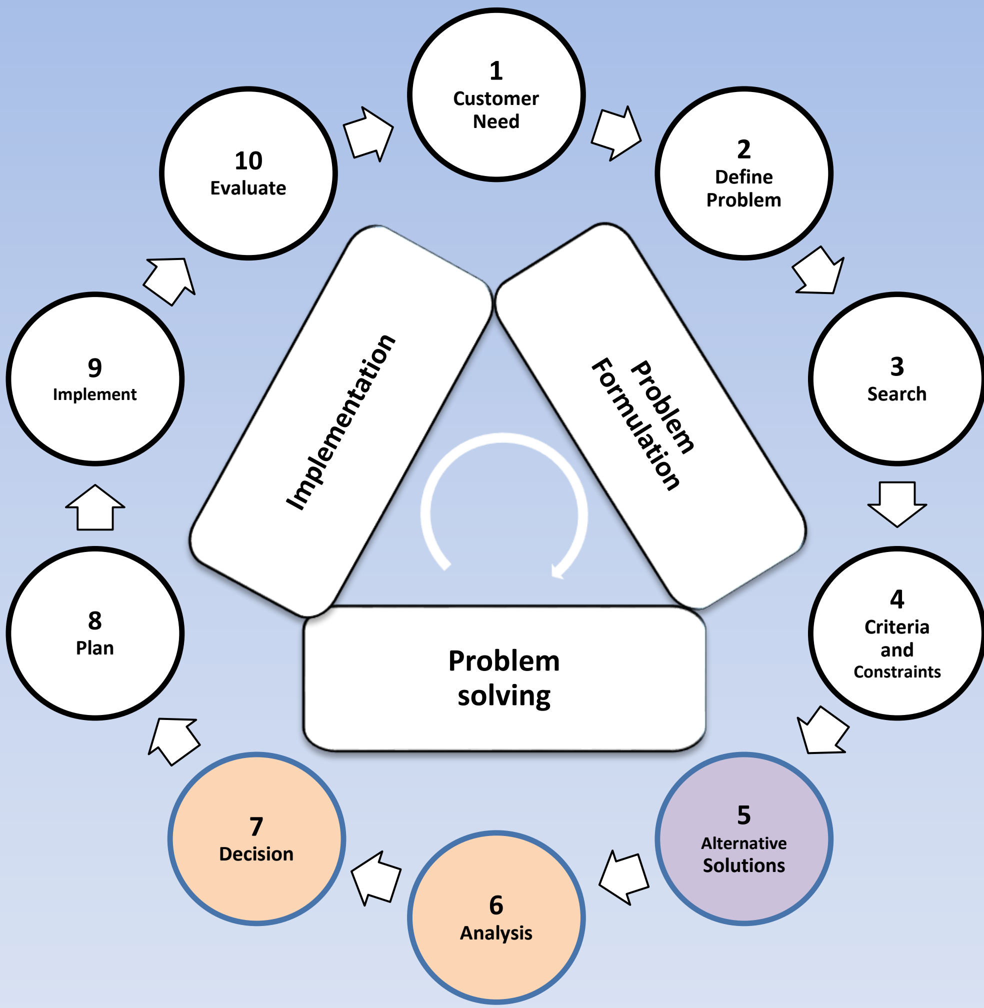
4 Flat Reflectors Open Corners

4 Flat Reflectors Closed Corners

Concept Evaluation Based on Criteria

- **Characteristics of Engineering Decisions:**
  - Multiple criteria
  - Criteria are of different importance
  - Criteria are conflicting
  - Multiple interested parties

- **Use a Decision Matrix:** A simple decision approach to weigh pros and cons applying weight and rate concept (multiply and sum)



Applying Weight-and-Rate

- Features/attributes of the Solar Oven viewed as **important**:
  - ✓ Direct Energy into Oven
  - ✓ Easy to Manufacture
  - ✓ Room for Error in Aim
  - ✓ Hold Energy in Oven
  - ✓ Durable (Durability)
  - ✓ …

- Keep attributes as independent as possible, Do not repeat any attribute or criteria! This will ensure an objective evaluation.

Weights

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- To determine the importance of each attribute, we use a simple approach based on weights that sum to 100.

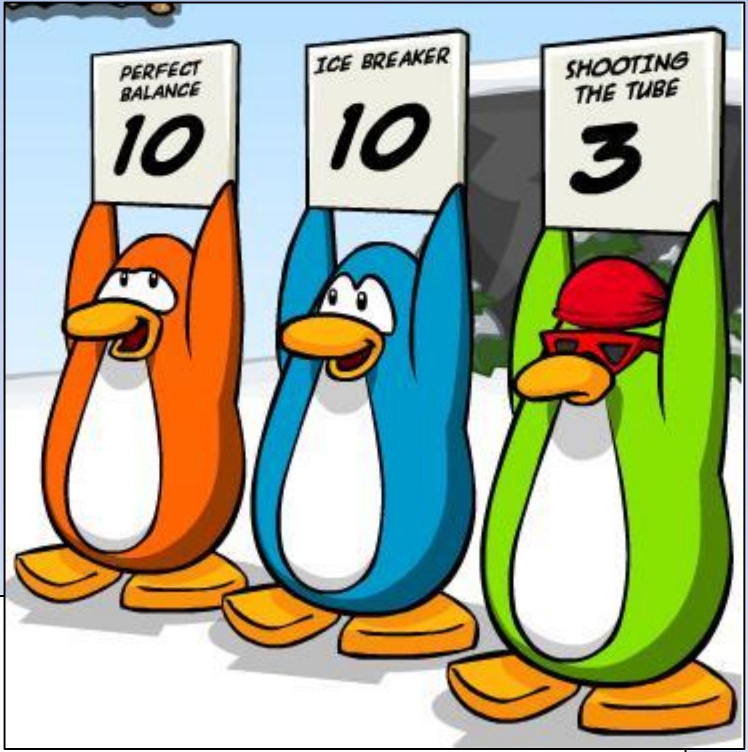
Evaluation Criteria	Direct Energy	Manufacturability	Flexibility	Holding Energy in Oven	Total Weight
Scenario 1: Compromise	25	25	25	25	100%
Scenario 2: Most light in	**40**	5	15	40	100%
Scenario 3: Easy to make	20	**40**	20	20	100%

Weights signify the relative importance of the evaluation criteria.

Rates

- **Once alternative concepts are determined, rate each attribute for each alternative concept on a scale from 1 (worst) to 10 (best)**

- **For the solar oven example, we will only use three alternative concepts* and four attributes**
- **Normally, you would have more concepts and more attributes**



attributes = criteria;
concepts = alternative solutions;
scenario = division of weights (e.g. compromise = equal weights);
rates = score for each attribute (1-10)

Rating the Concepts - Scenario 1 (*most light in*)

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- Let us use the "**most light in**" Scenario
- This scenario uses weights (**40, 5, 15, 40**)

Evaluation Criteria	Direct Energy	Manufactu rability	Flexibility	Holding Energy in Oven	Score
Weights→	**40**	**5**	**15**	**40**	
Concept 1: No reflector Big window	**1**	**10**	**5**	**3**	
	40	**50**	**75**	**120**	**285**
Concept 2: 1 reflector Small window	**4**	**8**	**7**	**6**	
	160	**40**	**105**	**240**	**545**
Concept 3: Parabolic	**9**	**2**	**4**	**4**	
	360	**10**	**60**	**160**	**590** ★

Rating the Concepts – Scenario 2 (*Compromise*)

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- Let us use the "**compromise**" Scenario*
- This scenario uses weights (***25, 25 , 25, 25***)

Evaluation Criteria	Direct Energy	Manufacturability	Flexibility	Holding Energy in Oven	Score
Weights→	25	25	25	25	
Concept 1: No reflector Big window	**1**	**10**	**5**	**3**	
	25	**250**	**125**	**75**	**475**
Concept 2: 1 reflector Small window	**4**	**8**	**7**	**6**	
	100	**200**	**175**	**150**	**625**
Concept 3: Parabolic	**9**	**2**	**4**	**4**	
	225	**50**	**100**	**100**	**475**

Final Remarks

- **Decision matrices (weight-and-rate) are helpful tools for exploring trade-offs.**

- **Use more than one scenario and do not be driven by a single-objective mentality.**

- **You do not necessarily have to use the one with the highest score.**

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