Solar Heating of Insulated Container

User Manual

ZEUS NUMERIX

Defense | Nuclear Power | Aerospace | Infrastructure | Industry

August 2020

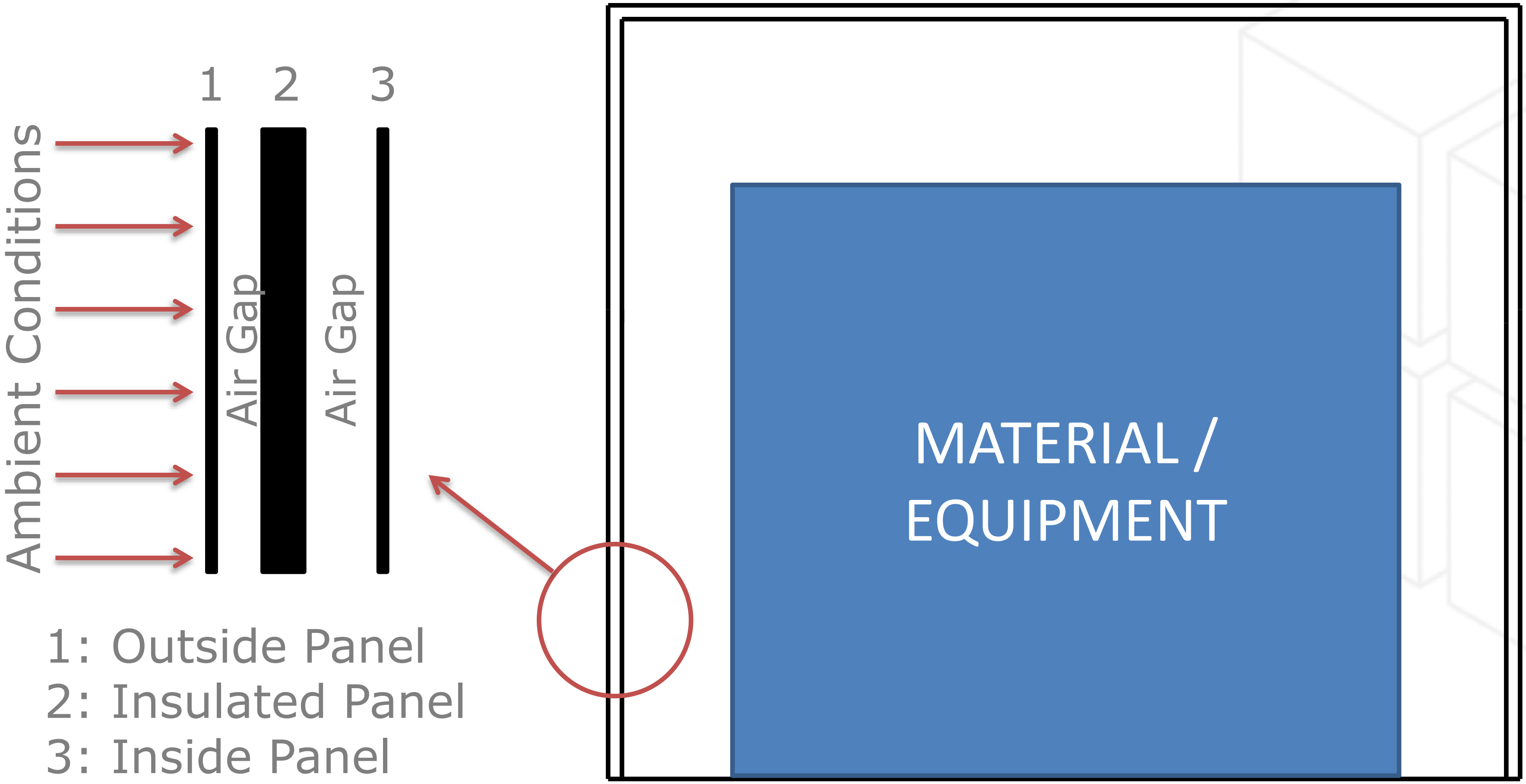
Content

- **Problem Statement**
- Theoretical Approach
- Inputs & Results

Problem Statement

- Insulated containers are used for transport machineries and equipment.
- There are concerns that temperature inside the container may reach extreme values (>55^{o}C) when exposed under sun in summer days.
- The objective is to get an estimate on temperature values that will be attained inside the insulated container.

Insulated Container Construction



1: Outside Panel
2: Insulated Panel
3: Inside Panel

Underlying Physics

- The outer surface of container interacts with ambient on two counts: (1) Radiant solar flux during the day (2) Free convection from ambient air

- Panel materials & air gaps will provide insulation by way of absorbing, reflecting back or delaying the transfer of heat from outside to inside.

- Overall, there will be heating of container (all layers + equipment) during the day & cooling down during nights. This diurnal variation of container temperature is to be predicted.

Content

- Problem Statement
- **Theoretical Approach**
- Inputs & Results

Theoretical Approach

- Lump parameter model is utilized.
- It estimates the temperature on outer panel, insulated panel, inner panel, internal air & equipment.
- For each of the above component, instantaneous heat transfer rate from neighboring elements is estimated. Heat transfer rate is integrated in time to get instantaneous component temperature.

- Starting from an assumed temperature value, the approach is followed for multiple diurnal cycles, till a consistent daily variation is obtained.

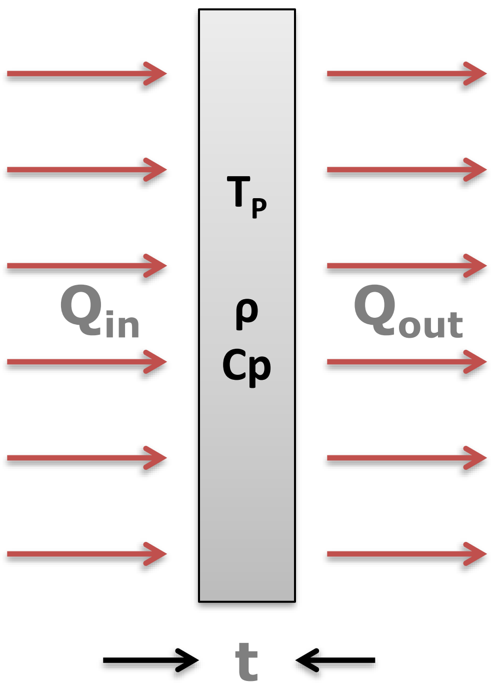
Key Assumptions

- Heat transfer in panel is through the thickness only. Heat conduction along the panel surface (transverse direction) is ignored.

- Natural convection of air inside the container is strong enough to achieve a uniform bulk temperature of air.

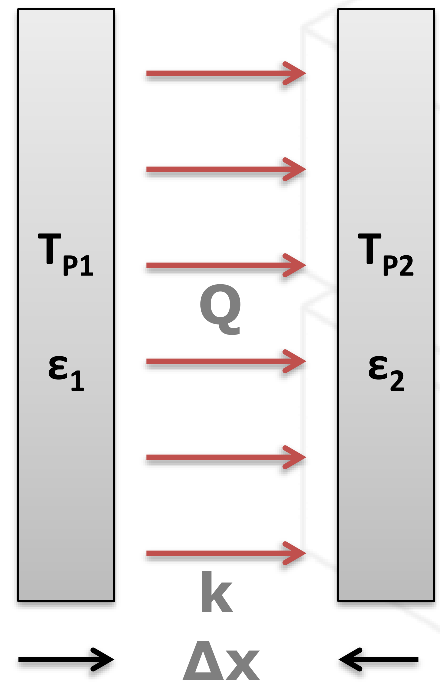
Heat Balance Equations

For Panels



$$\rho.t.A_P.C_P\left(T_P^{n+1}-T_P^{n}\right)=\left(Q_{in}-Q_{out}\right)$$

For Air Gaps



$$Q = k.A_P.\frac{\left(T_{P2}-T_{P1}\right)}{\Delta x} + A_P\frac{\sigma\left(T_{P2}^4-T_{P1}^4\right)}{1/\varepsilon_1+1/\varepsilon_2-1}$$

Heat Balance Equations

- For Internal Container Air

$$\rho_{air}.V_{air}.C_P\left(T_{air}^{n+1}-T_{air}^{n}\right)=\left(\sum_{n=1}^{7}Q_{in}\right)-Q_{article}$$

where $Q_{in}=h_{in}.A_P\left(T_{P,inner}-T_{air}\right)$ by convection

- For Equipment

$$\left(m_{equipment}C_{P,equipment}\right)\left(T_{equipment}^{n+1}-T_{equipment}^{n}\right)=Q_{equipment}$$

where $Q_{equipment}=h_{in}.\left(A_{equipment}\right)\left(T_{air}-T_{equipment}\right)$

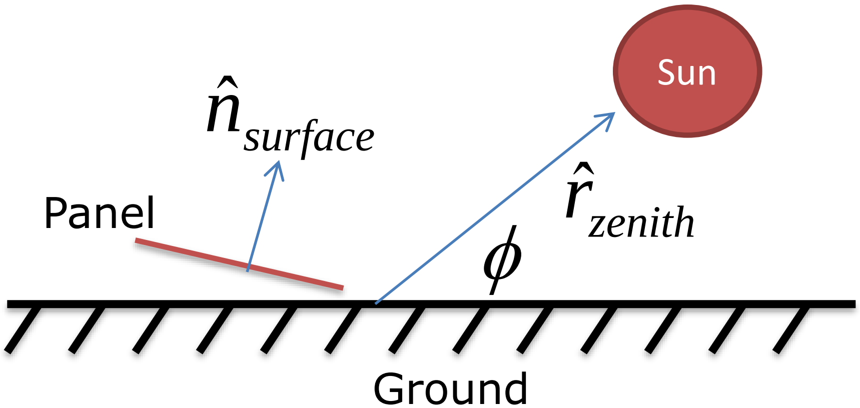
Solar Flux

- On Outer Panel Surface

$$Q_{ambient} = h_{ambient}.A_P.\left(T_{ambient} - T_{P,outer}\right) + A_P.\sigma.\varepsilon_P\left(T_{ambient}^4 - T_{P,outer}^4\right) + Q_{solar}$$

- Solar flux is calculated based on zenith angle of sun & unit normal of the panel surface

$$Q_{solar} = A_P.I.\left(\hat{r}_{zenith}.\hat{n}_{surface}\right)$$



Solar Flux

- Solar flux entering atmosphere is I_0 (1366W/m^2). It attenuates before reaching ground, proportional to length of path traversed inside atmosphere.
- Attenuation is maximum around sun-rise / sun-set when zenith angle is 0^o. Atmospheric attenuation is minimum when zenith angle is 90^o.
- Mathematically,

$$I = I_0 e^{\left(-\alpha / \sin\phi\right)}$$

- Zenith angle increases linearly in time from sun-rise to middle of day. Similarly, zenith angle decreases linearly till sun-set.

Solar Flux

- Solar power at any geographical location is given as daily solar radiant flow, P_{daily}, in $MJ/m^2/day$. For tropical deserts, its peak is 25.1 $MJ/m^2/day$ in May.
- Mathematically,

$$P_{daily} = \int_{t=sun\_rise}^{t=sun\_set} I.\cos\phi.dt$$

- Above relation is used to calculate attenuation constant, α, for a given value of daily solar radiant flow.

Content

- Problem Statement
- Theoretical Approach
- **Inputs & Results**

Canopy Design Data

Parameter	Value
Container Length	6.06 m
Container Height	2.59 m
Container Base Width	2.43 m
Container Top Width	2.40 m
Container Slant Angle	45°
Equipment Length	1.0 m
Equipment Diameter	1.0 m
Equipment Thickness	100 mm
Frame Mass	0 kg
Frame Surface Area	0 m^2

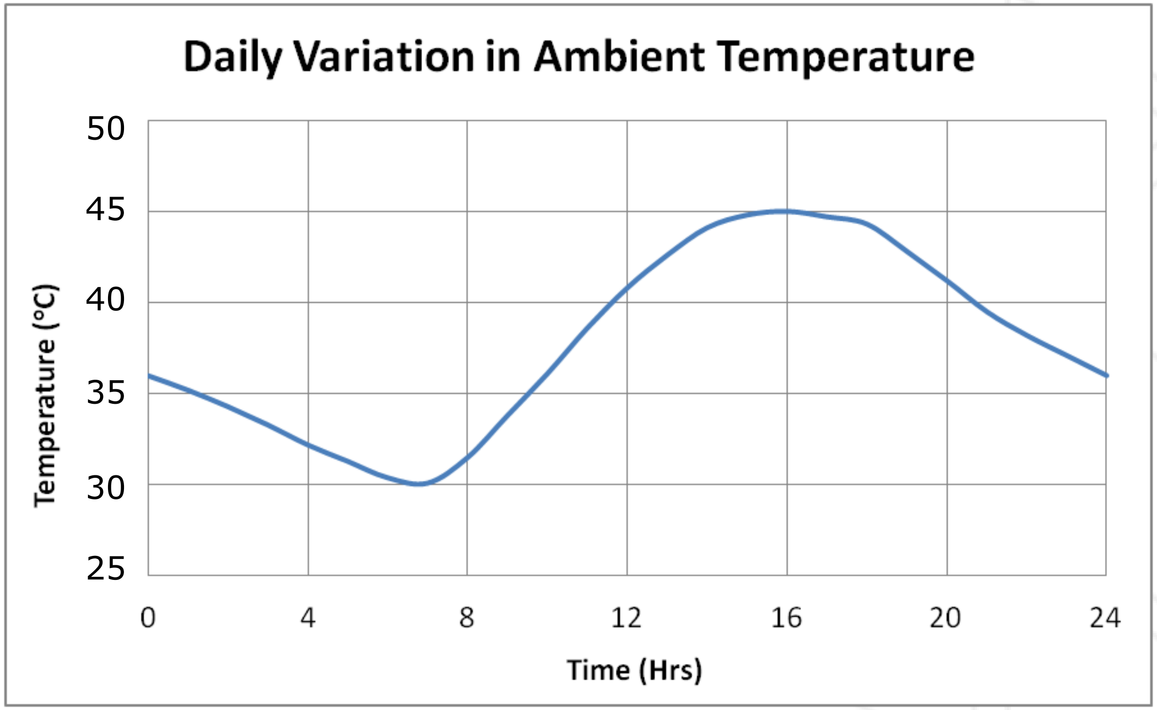
Parameter	Value
Outer Panel Thickness	1 mm
Inner Panel Thickness	1 mm
Insulation Thickness	20 mm
Outer Air Gap Thickness	6 mm
Inner Air Gap Thickness	14 mm

Material Properties

Component	Material	Density	Specific Heat	Emissivity	Conductivity
Equipment	Steel	7800 kg/m^3	500 J/Kg/K	-	-
Frame	Steel	7800 kg/m^3	500 J/Kg/K	-	-
Outer Panel	Steel	7800 kg/m^3	500 J/Kg/K	0.6	-
Inner Panel	Aluminum	2700 kg/m^3	900 J/Kg/K	0.1	-
Insulated Material	Non Metal	1000 kg/m^3	1900 J/Kg/K	0.9	0.5 W/m/K

Ambient Conditions

Parameter	Value
Sun Rise Time	7 hr
Sun Set Time	19 hr
Daily Solar Exposure	25.1 $MJ/m^2/day$
Daily Max. Temperature	45°C
Daily Min. Temperature	30°C
h, Ambient	10 $W/m^2/K$
h, Interior	5 $W/m^2/K$



Parameter	Value
Time Steps per Day	12000
Simulation Days	10 Days

Results

- Peak Temperatures attained during the day are:
  - Equipment: 47.2^oC
  - Internal Air: 58.9^oC
  - Inner Panel: 63.9^oC
  - Inner Surface of Insulation: 72.8^oC
  - Outer Surface of Insulation: 73.8^oC
  - Outer Panel: 78.9^oC

- The fraction of heat transferred from SS panels (outer surface) to Internal Air is 0.95%.

Output

- The software execution generates a detailed output file
- This file contains time history of all important container thermal parameters. These are:

Temperature (^oC)	Heat Transfer (W)
Ambient	Solar Flux Absorbed by Outer Panel
Outer Panel	Heat Loss to Ambient by Convection & Radiation
Insulation Outer Surface	Heat Transfer through Outer Gap
Insulation Inner Surface	Heat Transfer through Inner Gap
Inner Panel	Heat Transfer to Internal Air
Container Internal Air	Heat Transfer to Article / Frame
Equipment	

- The above parameters are also plotted

Thank You!

ZEUS NUMERIX