E355 : Cold Chain Management

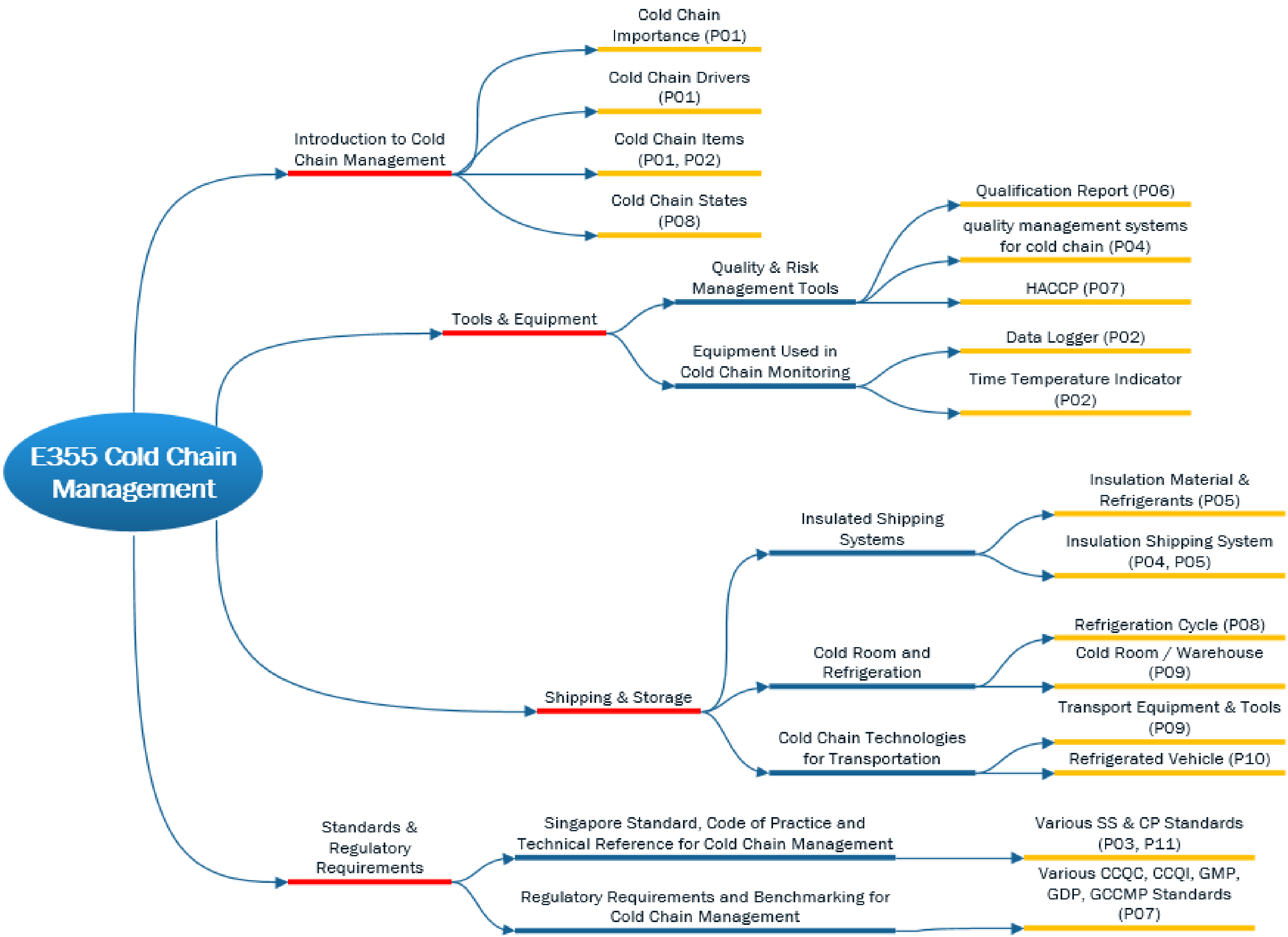
Problem 04

Choose the best cold box

- Describe and explain the 3 methods of heat transfer
- Identify the common materials suitable for insulation and discuss the criteria for selection
- Describe the experiment procedures to determine the resistivity of an insulated shipping system
- Compute the **System R-value** and Heat Penetration Rate (**HPR**) for insulation boxes

SCHOOL OF ENGINEERING

E355 Cold Chain Management - Topic Tree



Cold Chain Shipping System

A cold chain shipping system commonly consists of the following parts:

1. Outer Carton – to protect and hold the items inside, labeling

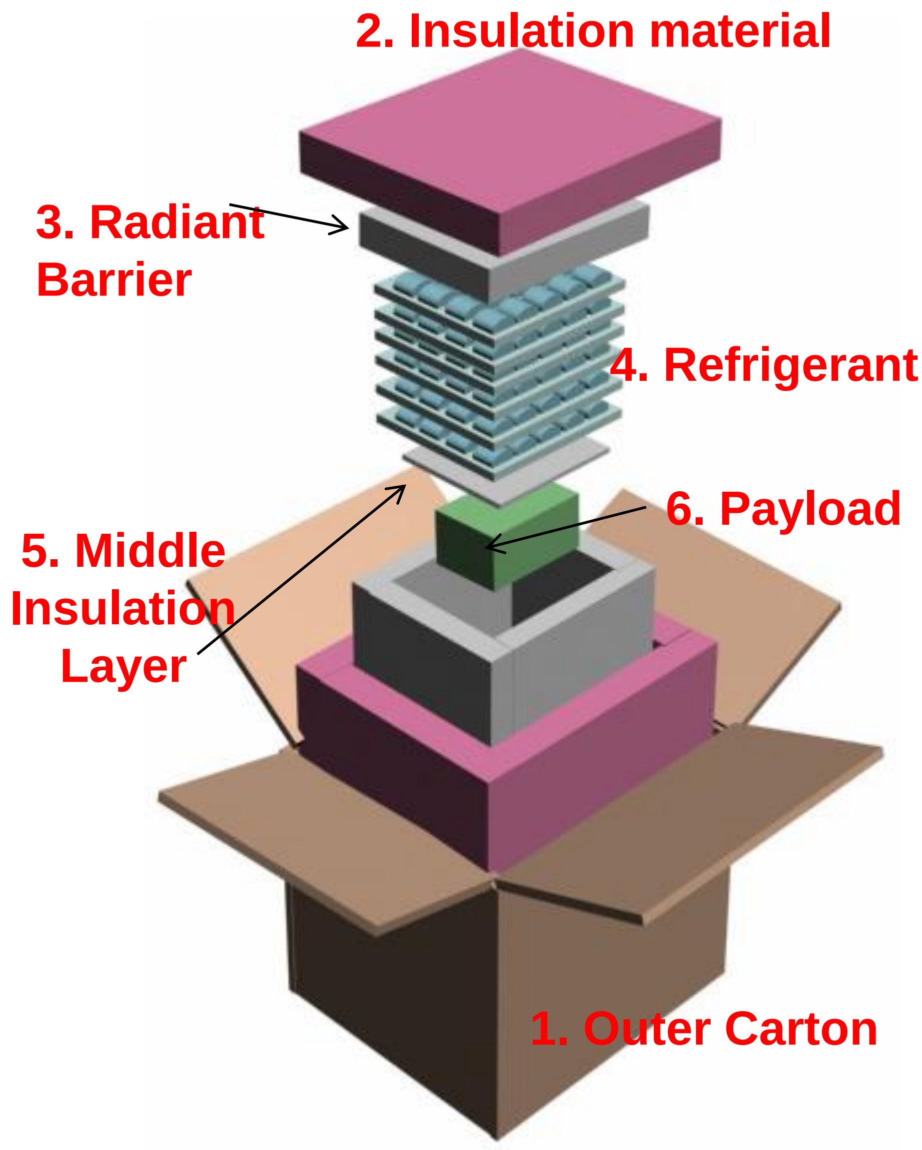
2. Insulation Material – to minimize heat absorbed from the surrounding

3. Radiant Barrier – to reduce effects of radiation

4. Refrigerant – cooling substance to maintain internal temperature

5. Middle Insulation Layer – to separate the payload and the refrigerant and reduce radiation effects

6. Payload – product to be shipped

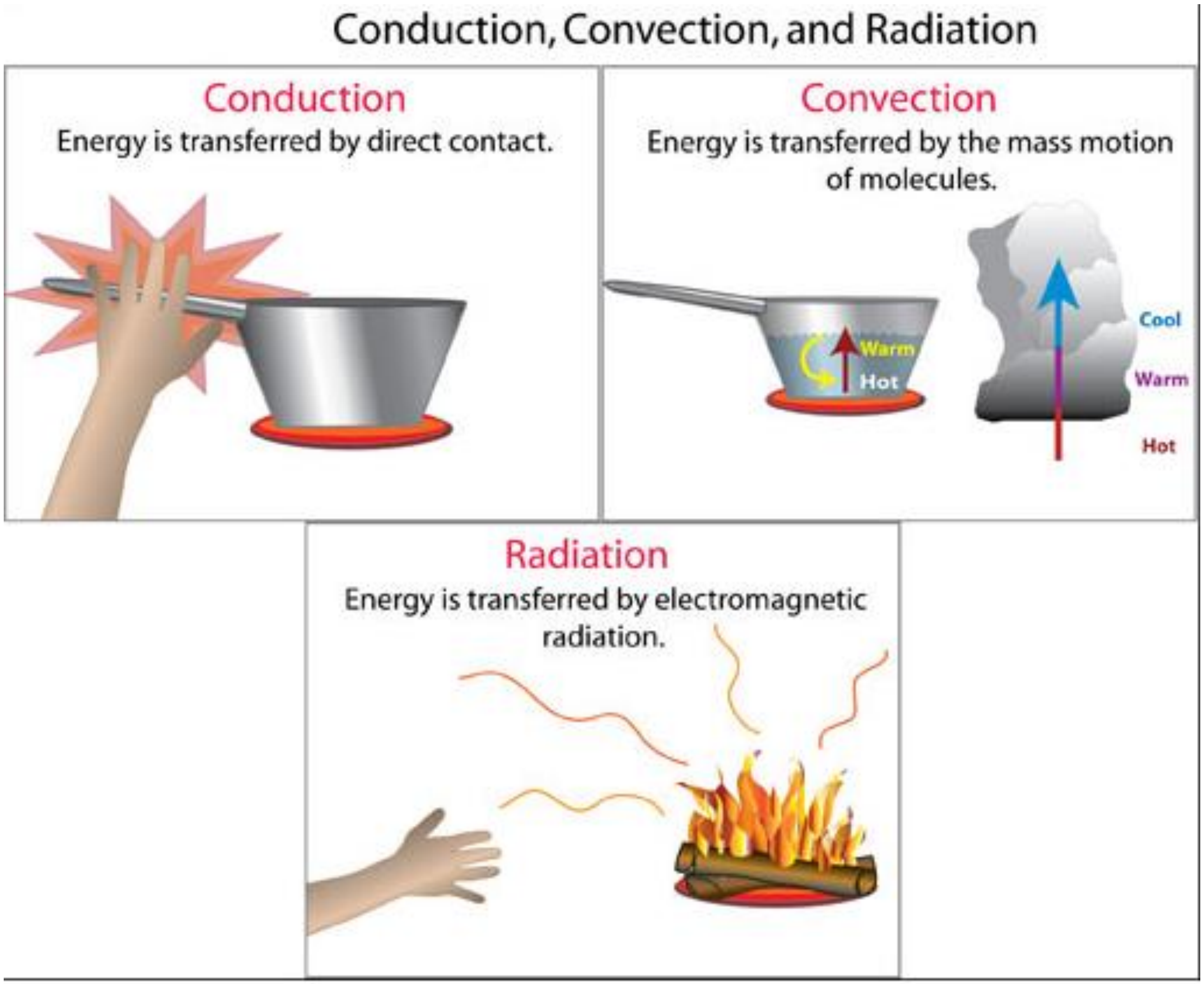


Heat Transfer

- The function of the insulation material is to prevent heat transfer from the surrounding environment into the payload.
- Heat can be transferred through Conduction, Convection and Radiation
- Most insulating materials utilize low thermal conductivity as a means of restricting the transfer of heat through conduction, although radiation and convection are also significant
- For packaging applications: low cost, low moisture susceptibility, ease of fabrication and transportation, consumer appeal, and mechanical strength are factors to consider when selecting a suitable packaging materials

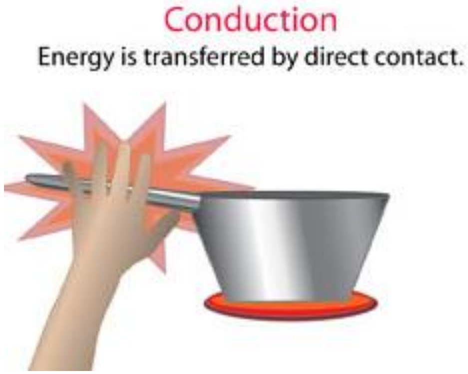
Heat Transfer

- Illustration of heat transfer



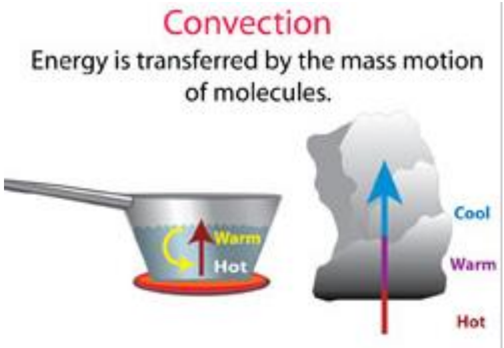
Conduction

- Conduction is due to direct molecular communication within a medium (insulation material) without any motion of the material as a whole.
- The ability of a material to conduct heat is known as the **thermal conductivity, k**. The lower the thermal conductivity, the better is the insulation
- The thicker the material and the smaller the surface area, the lower the effects of conduction



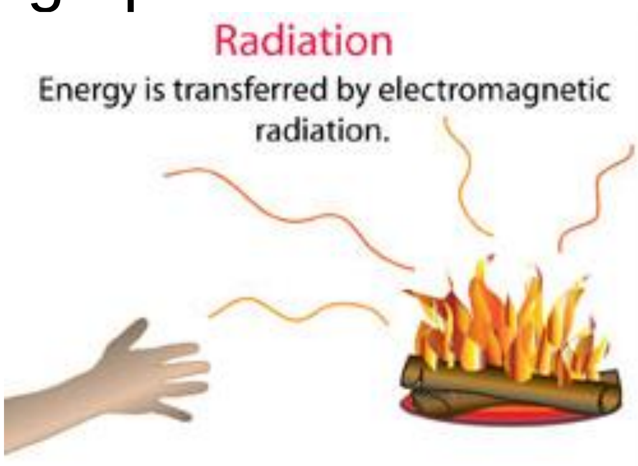
Convection

- Convection is due to fluid circulation such as air or water, or movement of the hot particles to cooler areas in a material medium
- Insulation greatly retards natural convection, which occurs due to changes in air density with temperature, by trapping air inside, as air is a good insulator
- In standard insulation foam, a high-density foam will have a greater number of air-trapping cells than a low-density foam



Radiation

- Radiation is transfer of heat through electromagnetic waves
- No medium is required; a black body absorbs most heat as compared to a shiny silvered surface which absorbs least
- Radiation can be restricted using a material with high reflectivity such as aluminum foil, as reflective surfaces have low emittance and block a large portion of radiant heat flow



Insulation Material

- Thermal resistance (**R-value)** is used for calculating the thermal resistance of any material or composite material. It can be defined in simple terms as the resistance that any specific material offers to the heat flow. The higher the R-value, the greater the insulation.
- Common insulation materials include:
  - Polyurethane
  - Polystyrene
  - Vacuum Insulated Panel (VIP)

Polyurethane

- PUR (Polyurethane) is a highly effective solution for many temperature-sensitive shipments
- Less frequently utilized because of their cost, but the insulation value of PUR is much higher than that of EPS (Expanded Polystyrene)

<u>Advantages</u>

- High R-value
- Rigidity
- Smaller size
- Inexpensive tooling cost
- Reusability

<u>Disadvantages</u>

- Non-recyclable
- High cost
- Slow production speed
- Weight

Polystyrene

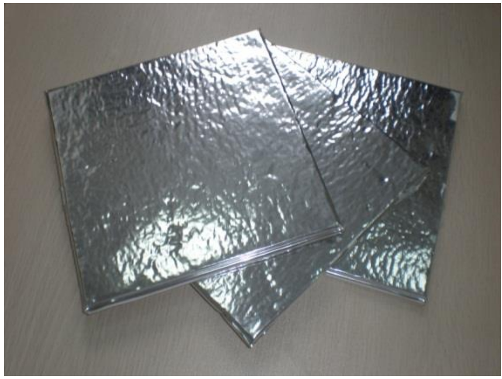
- EPS (Expanded Polystyrene) and XPS (Extruded Polystyrene) are cost-effective solutions for many temperature-sensitive shipments
- Commonly known as 'Styrofoam', but Styrofoam® is a trade name for an extruded building material made by Dow Chemical
- Comes in molded or 6-panel; depending on need for flexibility, cost concerns and performance (although a static test on both types do not reveal any significant difference)

Advantages
- Lower cost
- Less weight
- Mass Production
- Recyclable
- Re-usable

Disadvantages
- Low R-value
- Higher fragility
- High mold cost

Vacuum Insulated Panel (VIP)

- VIP (Vacuum Insulated Panel) have the highest insulation value of all containers available on the market for small shipments
- Generally the most expensive container when compared to other materials
- Available ones in the market are not molded; they are constructed by assembling 5 VIPs for the base and using the sixth panel for the lid, with the base panels taped together to eliminate any air gaps
- In order to protect the VIPs, manufacturers will often surround the panels with a buffer material such as EPS panels or flexible foam



Vacuum Insulated Panel (VIP)

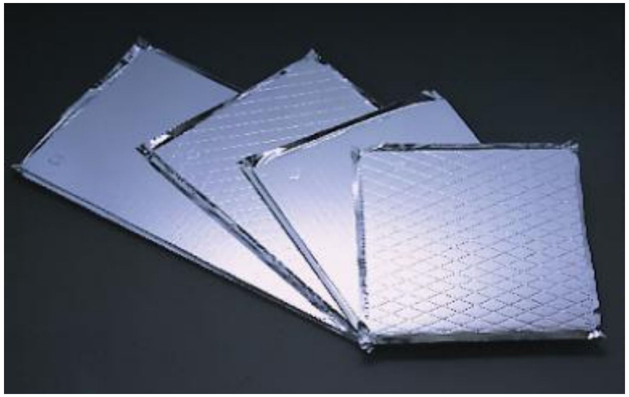
- The core of the VIP is used to provide physical support, and to interrupt the flow of heat; common materials include Perlit, mineral powder, fiberglass and silica
- Membrane films form the walls of the VIP, and provide an effective barrier against all atmospheric gases and moisture
- Getters and desiccants are included in the panels to absorb gases and moisture respectively

<u>Advantages</u>

- High R-value
- Low shipping weight
- Reusable

<u>Disadvantages</u>

- High cost
- Durability
- Availability



Comparison of Insulation Materials

Material	Thermal Conductivity, k, at 23°C (W/m°C)	Thermal Resistivity, R-value per mm at 23°C (m^2°C/Wmm)
Air	0.026	0.0386
Corrugated Board	0.061	0.0165
Polyurethane (PU)	0.03	0.0321
Polystyrene (EPS)	0.038	0.0262
Vacuum Insulating Panel (VIP)	~0	0.0694 – 0.2038

- The thermal conductivity of a material may depend on temperature.
- The reciprocal of thermal conductivity is called thermal resistivity (R-Value).

Ice Melt Test

The principle of the ice melt test is based on the fact that 1kg of ice must absorb 335kJ of heat to melt, and the procedures is as such:

1. A sufficient quantity of ice (e.g. 1kg) was placed in a non-metallic bucket and allowed to melt in room temperature

2. After about 2hrs, the water from the bucket was drained; at this point of time, ice is at its melting temperature of 0°C, and not the freezer temperature at which it was stored

3. The bucket was then placed in the centre of the cold box and sealed, leaving it in the ambient temperature for 4hrs

4. After 4hrs, the water that has melted from the ice in the bucket was weighed and used to calculate the melt rate (kg/h),

Melt Rate (kg/h) = Weight of water collected (kg) / test time (h)

Source: Performance Comparison of Thermal Insulated Packaging Boxes, Bags and Refrigerants for Single-Parcel Shipments, by S.P. Singh, Gary Burgess and Jay Singh, Wiley Inter-Science, 13 Mar 2007.

System R-value

- The **System R-value** includes the size and shape of the container, the wall material and thickness, and to some extent, the effect of the product. As such, it is the property of the whole package (cold box), and not just the insulating material (R-value).
- System R-value = $\frac{\text{(Inside surface area) x (Temperature difference)}}{\text{(Melt rate) x (Latent heat of ice)}}$

  where (1) surface area = inside surface area of package (m^2)

  (2) temperature difference = ambient temperature - melting point of ice (e.g.25^oC - 0^oC = 25^oC)

  (3) Melt rate: kg/hour

  (4) latent heat = 335 kJ/kg
- Units of System R-value: m^2K/W or $m^{2o}C/W$ (W is power unit: watt)

Example of Computation of System R-value

B1 has dimensions 0.12L x 0.16W x 0.22H in metre

Surface area = 2*(0.12*0.16) + 2*(0.12*0.22) + 2*(0.16*0.22)

= $\underline{0.162\ \text{m}^2}$

Temp diff = ambient temp – melting temp = 25 – 0 = 25°C

Melt rate = 0.11 / 4 = 0.026 kg/h

Latent heat of ice = 335 kJ/kg

System R-value

$$= \frac{0.162 \times 25}{0.026 \times 335}\ \frac{\text{m}^2\,{}^\circ\text{C}}{(\text{kg/h})(\text{kJ/kg})}$$

$$= 0.046\ \frac{\text{m}^2\,{}^\circ\text{C}}{(\text{kJ/h})}$$

$$= 0.046\ \frac{\text{m}^2\,{}^\circ\text{C}}{1000\text{J}/3600\text{s}}$$

$$= 0.046\,\frac{3.6\ \text{m}^2\,{}^\circ\text{C}}{\text{J/s}}$$

$$= 1.658\ \text{m}^2\,{}^\circ\text{C/W}$$

Note: 1 W = 1 J/s (Joule/second)
Or 1 W = 3.6 kJ/h

Heat Penetration Rate

- Heat Penetration Rate (HPR) can be used to quantify the insulating ability of a package, irrespective of the size of the package
- It is defined as the rate in Watts at which heat penetrates the container per degree of temperature difference between the outside and inside air
- $$\text{HPR} = \frac{\text{Inside Surface Area of container}}{\text{System R-value}}$$

  Units of HPR: W/K or W/°C

- Example: Box B1

  Inside Surface Area of container = 0.162 m^2

  System R-value = 1.658 m^2°C/W

  HPR= 0.162/1.658 = 0.097 W/°C

Today’ Problem - Performance Comparison

S/N	Box Name	Radius or Length [m]	Width [m]	Height [m]	Inner Surface Area [m2]	Starting Temp	Final Temp	Temp Difference	Weight of ice melted [kg]	Melt Rate [kg/h]	System-R [m2°C/(kJ/h)]	System-R [m2°C/W]	HPR [W/°C]
1	B1	0.12	0.16	0.22	0.162	25	**0**	25	**0.11**	**0.026**	0.460	**1.658**	**0.097**
2	B2	0.25	0.26	0.24	0.375	25	**0**	25	**0.17**	**0.040**	0.691	**2.488**	**0.151**
3	B3	0.21	0.31	0.25	0.390	25	**0**	25	**0.18**	**0.043**	0.679	**2.446**	**0.160**
4	B4	0.27	0.31	0.31	0.527	25	**0**	25	**0.19**	**0.045**	0.869	**3.130**	**0.168**
5	B5	0.29	0.19	0.17	0.273	25	**0**	25	**0.16**	**0.038**	0.536	**1.928**	**0.142**

The higher the System-R value, the better the insulation performance of the box. Hence, the B4 is the best cold box with the highest System-R value.

Today's Problem

- The function of the insulation material in the cold box is to prevent heat from entering the inside of the box, thus causing internal temperature to rise
- The performance of the boxes are affected by the material used for insulation, the size of the box and whether a shiny surface was used.
- From the results of the ice-melt test, you can compute the system R-value and heat penetration rate of the different thermal insulated boxes. The higher system R-value, better insulation performance of the box
- Besides the insulation performance, the cost of the cold box, transportation duration, the value of the product, etc. may be considered in making the selection decision.

Learning Objectives

- Describe and explain the 3 methods of heat transfer
- Identify the common materials suitable used for insulation and discuss the criteria for selection
- Conduct the experiment procedures to determine the resistivity of an insulated shipping system
- Compute the System R-value and Heat Penetration Rate (HPR) for insulation boxes