CEM | CEA

AN INTRODUCTION TO BUILDING ENVELOPE

Learning Facilitator:

Learning Objectives

- Define building envelope and building load.
- Use heat flow equations to calculate transfers by transmission, solar gain, infiltration and ventilation.
- Identify gains from people and equipment.
- List and describe methods of minimizing load and losses through the building envelope.

INTRODUCTION

The building envelope is a **critical component** of any facility since it protects the building occupants and plays a **major** role in regulating the **indoor** environment.

INTRODUCTION

Building envelope consisting of the building's **foundation, walls, roof, windows, partitions, ceilings** and **doors**.

Energy Management Significance

Accurate assessment of the building envelope performance is **crucial** for **effective** facility-wide energy management.

Energy Management Significance

Some critical factors that can affect envelope performance:

- Actual Installation Conditions
- Impact of Conductive Elements
- Role of Thermal Mass

Thermal Energy Transfer

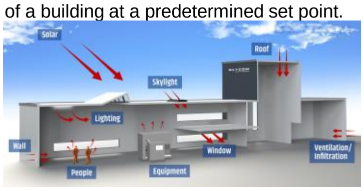
- Refer to heat lost from or gained by a building.

Heat loss - indoor temperatures that are warmer than outside

Heat gain - indoor temperatures that are cooler than outside.

Building Load

- refers to the amount of heat required to be **removed**, or **added**, to maintain the internal temperature and humidity of a building at a predetermined set point.



Design Cooling Load

…is the amount of heat energy to be removed from a building by the HVAC equipment.

Sensible Cooling Load

…a Sensible Cooling Load are referring to the dry bulb temperature which is measured by standard space temperature sensors.

Sensible Cooling Load Factors Include:

- Doors and windows
- Sunlight on windows and glass doors
- Exterior walls
- Partitions
- Plenums
- Roofs
- Air infiltration
- People
- Equipment and appliances
- Lights
- Ductwork
- Air ventilation

Latent Cooling Load

… is a measure of the amount of energy that is necessary to **dehumidify** the air in a building.

Latent cooling load refers to the **wet bulb** temperature.

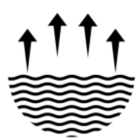
Latent Cooling Load Factors Include:

- People breathing
- Equipment and appliances
- Air infiltration due to unconditioned outside air



Enthalpy

...is the energy from both sensible and latent heat. In the case of air, it includes the heat due to the temperature, and the heat contained in any evaporated water.



Mathematical Representation:

$H = U + PV$

Where:
H is the enthalpy,
U is the internal energy
P is Pressure
V is Volume

External Loads

OVERALL HEAT TRANSFER

- Heat transfer through transmission
- Heat transfer through solar gain through glass
- Heat transfer due to ventilation
- Heat transfer due to infiltration

External Loads

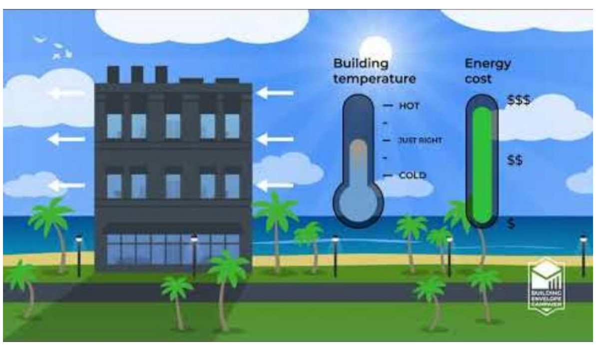
Overall Heat Transfer

Mathematical Representation:

$H = H_t + H_S + H_v + H_i$

Where:

H = overall heat transfer (W or Btu/hr)
H_t = heat transfer due to transmission through the surfaces of walls, windows, doors, floors and more (W or Btu/hr)
H_s = heat transfer due to solar gain through glass (W or Btu/hr)
H_v = heat transfer caused by ventilation (W or Btu/hr)
H_i = heat transfer caused by infiltration (W or Btu/hr)



Heat Transfer by Transmission

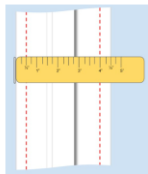
Basic Equation:

$\mathbf{H_t = A\ U\ (t_o - t_i)}$

where:
H_t = transmission heat loss (W or Btu/hr)
A = area of exposed surface (m^2 or ft^2)
U = heat transmission coefficient ($W/m^2\ K$ or $Btu/hr\ ft^2\ °F$)
t_i = inside air temperature (°C or °F)
t_o= outside air temperature (°C or °F)
Also written as $\mathbf{H_t = A\ U\ \Delta t}$.
Δt just refers to the difference in the inside and outside air temperatures.

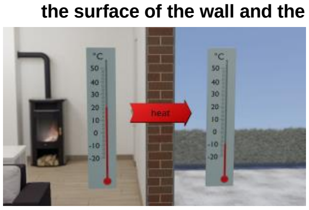
U-Value

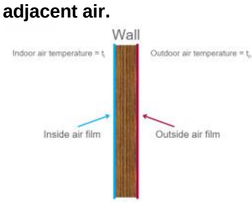
The type of material has an effect on the heat transfer.



U-Value

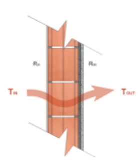
The heat also has to pass through a boundary between the surface of the wall and the adjacent air.





U-Value

U is the Overall Coefficient of Heat Transmission



- Represents the rate of heat flow through a unit area of building envelope material or assembly, including its boundary films, per unit of temperature difference between the inside and the outside air.
- Is commonly called the **"U-value".**
- Is expressed in watts per square meter per Kelvin (W/m^2 K) or Btu/hr ft^2 °F

U-Value

U value will change based on the type of **material** we are addressing. e.g. U value for a **window** will be different than the U value of a **door** or a **wall**.

	Material	U Factor	
		Btu/hr ft² °F	W/ m² K
Walls	Gypsum/Plaster Board – 1/2" or 12.5mm	2.25	12.8
	Sheet metal - 6" or 15cm Fiberglass Insulation	0.05	0.28
	Masonry - 8" or 20cm Brick	0.41	2.33
	Masonry - 12" or 30cm Brick	0.31	1.76
	Poured Concrete - 8" or 20cm	0.25	1.42
	Poured Concrete - 12" or 30cm	0.18	1.02
Doors	Single Sheet - Metal	1.2	6.81
	1" or 2.5cm - wood	0.65	3.69
	2" or 5cm - wood	0.46	2.61
Roofing	Corrugated metal - un-insulated	1.5	8.52
	1" or 2.5cm wood - un-insulated	0.5	2.84
	2" or 5cm wood - un-insulated	0.3	1.7
	1" or 2.5cm wood - 1" or 2.5cm insulation	0.2	1.14
	2" or 5cm wood - 1" or 2.5cm insulation	0.15	0.85
	2" or 5cm - concrete slab	0.3	1.7
	2" or 5cm - concrete slab - 1" or 2.5cm insulation	0.15	0.85
Windows	Vertical single glass	1.15	6.53
	Vertical double glass	0.7	3.97
	Horizontal single glass	1.4	7.95

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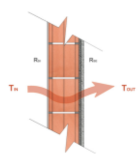
U-Value

Calculation of the U Value

$$U = \frac{1}{\left(\frac{1}{f_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + .. + \frac{1}{f_o}\right)}$$



where
f_i = surface conductance for inside wall (W/m²K or Btu/ft² °F)
x = thickness of material (m or ft)
k = thermal conductivity material (W/m²K or Btu/ft² °F)
f_o= surface conductance for outside wall (W/m²K or Btu/ft² °F)

where the surface conductance and thermal conductivities are found in common lookup tables.

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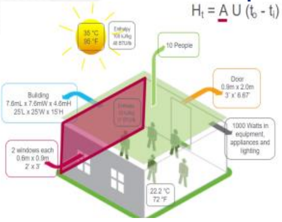
Example Calculation – Simple Wall

$H_t = A\ U\ (t_o - t_i)$



U-value =
0.57 W/m²K
0.1 Btu/hr ft² °F

$$H = U\ x\ A\ x\ \Delta T$$

$$H = \left(0.57 \frac{W}{m^2K}\right) x (7.6m x 4.6m)$$

$$x(35 - 22.2)°C)$$

$$H = 0.255\ KW$$

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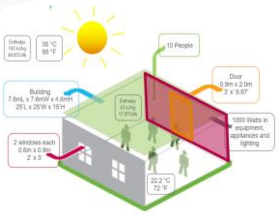
Example Calculation – Wall & Door



$$\left(\text{Heat transfer for } \text{The area of the wall} - \text{The area of the door} \right) + \left(\text{Heat transfer for } \text{The area of the door} \right)$$

$0.57 \frac{W}{m^2K}$ or $0.1 \frac{Btu}{hr\ ft^2\ °F}$

$3.69 \frac{W}{m^2K}$ or $0.65 \frac{Btu}{hr\ ft^2\ °F}$

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Example Calculation – Wall & Door

$$H = U\ x\ A\ x\ \Delta T$$

$$H = \left(0.57 \frac{W}{m^2K}\right) x \left((7.6x4.6) - (0.9x0.2)\ \right) m^2 x (35 - 22.2)°C)$$

$$Hwall = 0.242\ kW$$

$$H = U\ x\ A\ x\ \Delta T$$

$$H = \left(3.69 \frac{W}{m^2K}\right) x (0.9x0.2) m^2 x (35 - 22.2)°C)$$

$$Hdoor = 0.085\ KW$$

$$Htotal = 0.327\ kW$$

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Solar Gain Through Glass

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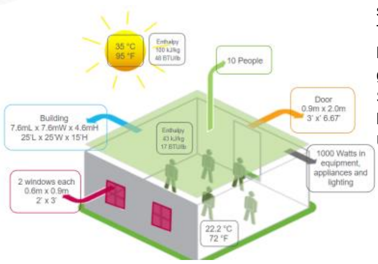
Solar Gain Through Glass

$H_s = A * SF * SC$

where:
H_s = solar heat gain through glass (W or BTU/hr)
A = area of glass (m^2 or ft^2)
SF = solar factor (W/m2 or Btu/hr ft2)
SC = shading coefficient

- Solar factor is the amount of heat per unit area entering the conditioned space through the glass, minus the percent of shading done by the structure of the glass.
- Shading coefficient is a factor of different types of glass and shading which accounts for the amount of radiation shaded from the conditioned space.

Solar Gain Through Glass



The building is at a latitude of **40°N**.
The windows face due south.
Two windows, single glazed, bronze tinted heat absorbing glass.
Shaded by a light venetian blind.
Use:

- Solar factor of **391** W/ m^2 or **124** BTU/ hr ft^2 (corresponding to noon)
- Shading coefficient of **0.52**

Example Calculation - Solar Gain (Metric)

Here's the metric calculation.

$H_s = A * SF * SC$

$H_s = (2 * 0.6 * 0.9) * 391 * 0.52$
$H_s = 1.08 * 391 * 0.52$
$H_s = 219.6$ W
H_s = **0.2 kW**

Ventilation

The heat transfers that take place as we ventilate a space.

Ventilation

The amount of heat consumed by ventilation depends on the volume of air and the difference in temperature and humidity.

Ventilation

Volume of air required for ventilation

- There is a requirement for the amount of air per person for example, cubic feet per minute (CFM) per person or cubic metres per hour (CMH) per person.
- The amount of air per unit area of floor space is specified, such as CFM per square foot or CMH per square meter.
- Building specifications require a certain number of air changes per hour.
  - The amount of air can be calculated from the volume of the building.

Sensible Heat Loss Due to Ventilation - Metric

Sensible heat loss due to ventilation without heat recovery

$$H_v = c_p \, \rho \, \frac{1}{3600} \, q_v \, (t_o - t_i)$$

where

H_v = ventilation heat transfer (W)

c_p = specific heat capacity of air (J/kg K) - 1005 J/kg K

ρ = density of air (kg/m^3) - 1.20 kg/m^3

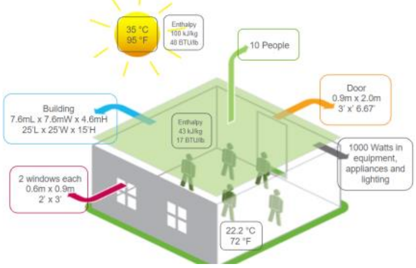
1/3600 = a value to convert from airflow per hour into joules per second, to obtain the result in watts

q_v = air volume flow (m^3/hr)

t_i = inside air temperature (°C)

t_o = outside air temperature (°C)

Example Calculation – Ventilation (Sensible Heat)



Example Calculation – Ventilation (Sensible Heat)

Here we see the detailed steps used to solve the equation.

$$H = \text{Cp x } \rho \text{ x Q x } (t_o - t_i)$$

$$H = \left(1.005 \frac{KJ}{kg\ K}\right) x \left(1.2 \frac{kg}{m^3}\right) x \left(10\ people\ x \frac{17\ m^3}{hr\ person}\right) x$$
$$x(35°C - 22.2°C) x \left(\frac{1\ hr}{3{,}600\ sec}\right)$$

$$H = 0.73\ KW$$

Infiltration

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Sensible & Latent Heat Loss for Ventilation or Infiltration - Metric

$$H_i = \rho \frac{1}{3600} q_v (h_o - h_i)$$

Where

H_i = heat transfer by infiltration (W)
ρ = density of air (kg/m^3)
1/3600 = a value to convert from airflow per hour into joules per second, to obtain the result in watts
q_v = air volume flow (m^3/hr)
h_i = inside air enthalpy (J / kg)
h_o = outside air enthalpy (J / kg)

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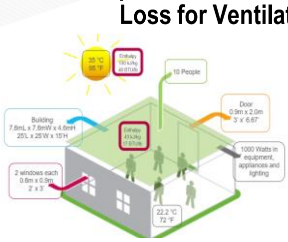
Example Calculation - Sensible & Latent Heat Loss for Ventilation or Infiltration



$$H = \rho \text{ x } Q \text{ x } (h_o - h_i)$$

$$H = \left(1.2\frac{kg}{m^3}\right) x \left(\frac{20\ m^3}{hr}\right) x (\ 100\text{-}43)\ \frac{KJ}{kg}\ x \left(\frac{1\ hr}{3{,}600\ sec}\right)$$

$$H = 0.47\ KW$$

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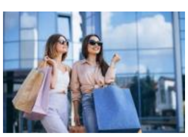
Internal Loads - People

People add quite a bit of **heat** to a space.

Internal Loads - People

BTUs/hr will need to be **adjusted** based on the **activity** in the space.



Internal Loads - People

Hp = 10 * 117
Hp = **1170 W or 1.170 kW**

Internal Loads - Equipment

- Most equipment located in a space will convert much of its power draw to heat.
- Tables of typical heat gains are available for different types of lighting and equipment.

Internal Loads - Equipment

- Our example building has 1000 W or 1 kW of heat gain due to equipment.
- In US units, this would be 3,412 BTU/hr.

Total Heat Load

External loads:	
• Heat transfer by transmission through the windows, doors, walls, roofs and floors	**0.255 KW , 0.327 KW**
• Solar gain through glass windows, glazed doors and skylights	**0.2 KW**
• Heat transfers from ventilation	**0.73 KW**
• Heat transfers from infiltration	**0.47 KW**
Internal loads:	
• Heat transfers from people	**1.17 KW**
• Heat transfers from equipment	**1.1 KW**
	Total : 4.252 KW

Improvements:

- **Insulate walls, roofs, and floors**
- **Upgrade windows and doors**
- **Seal all air leaks**
- **Install window shading**
- **Use reflective materials on roofs**
- **Add thermal mass**
- **Optimize building orientation and layout**
- **Integrate passive solar design features**
- **Implement advanced framing techniques**
- **Upgrade or install energy-efficient HVAC systems**
- **Area Specified Temperature and Humidity Control**

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Improvements:

1. Insulate Walls, Roofs, and Floors.

Adding insulation to these parts of the building envelope helps maintain indoor temperatures, reduces the energy required for heating and cooling, and enhances comfort. Materials like fiberglass, foam, or cellulose can be used, depending on the specific needs and building codes.

2. Upgrade Windows and Doors.

Replacing old, leaky windows and doors with energy-efficient ones that have good sealing and insulative properties (like double or triple-glazing with inert gas fill and low-emissivity coatings) can significantly cut energy losses.

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Improvements:

3. Seal All Air Leaks

Detecting and sealing gaps and cracks in the building envelope where air can infiltrate—such as around windows, doors, vents, and where different building materials meet—will reduce drafts and improve energy efficiency

4. Install Window Shading

Using awnings, overhangs, or high-reflectivity window films can prevent excessive solar heat gain through windows during warmer months, while allowing sunlight to help heat the home during colder periods

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Improvements:

5. Use Reflective Materials on Roofs

Materials that reflect sunlight, such as cool roof coatings or light-colored roofing materials, can keep buildings cooler by reflecting more sunlight and absorbing less heat.

6. Add Thermal Mass

Incorporating materials that can absorb and store heat energy (like concrete, brick, or stone) helps stabilize indoor temperatures by absorbing heat during the day and releasing it when temperatures cool.

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Improvements:

7. Optimize Building Orientation and Layout

Designing a building with its major axis running east-west can maximize natural light and heating from the sun, while minimizing overheating during summer months when the sun is higher in the sky.

8. Integrate Passive Solar Design Features

These features include using building elements like windows, walls, and floors to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer.

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Improvements:

9. Implement Advanced Framing Techniques.

Advanced framing with more space for insulation and less thermal bridging through wood can enhance the thermal resistance of the building envelope.

10. Upgrade or Install Energy-Efficient HVAC Systems.

While not a direct part of the building envelope, an efficient HVAC system, sized and installed correctly, complements the building envelope in maintaining comfortable indoor temperatures and air quality

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Improvements:

Area Specified Control

For heat from people, adopt personalized climate control and ventilation systems that adapt to individual needs for greater energy efficiency and comfort.

For heat from equipment, select energy-saving devices and design dedicated spaces to contain and repurpose excess heat, enhancing overall energy performance.

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KNOWLEDGE REVIEW

(Select the best answer)

1. What is building envelope?
   a. The boundary separating the inside from the outside and through which heat is transferred.
   b. The area where people work in a building.
   c. The area where the HVAC system is located in a building.

KNOWLEDGE REVIEW

(Select the best answer)

2. **What is the purpose of the building envelope?**
a. To provide fresh air to the occupants.
b. To regulate the indoor environment.
c. To provide lighting to the occupants.

KNOWLEDGE REVIEW

(Select the best answer)

3. What are the components of the building envelope?

a. The building's foundation, walls, roof, windows, partitions, ceilings, and doors.
b. The HVAC system, lighting, and furniture.
c. The flooring, paint, and wallpaper.

KNOWLEDGE REVIEW

(Select the best answer)

4. What is the definition of building load?

a. The amount of heat required to be removed or added to maintain the internal temperature and humidity of a building at a predetermined set point.
b. The amount of people and equipment in a building.
c. The amount of fresh air needed to be supplied to a building.

KNOWLEDGE REVIEW

(Select the best answer)

5. What are the factors that influence building load?

a. Heat transfer through transmission, solar gain, infiltration and ventilation, gains from people and equipment.
b. The color of the walls, the type of flooring, and the type of furniture.
c. The number of windows, the type of lighting, and the type of HVAC system.

KNOWLEDGE REVIEW

A large picture window in a home overlooks a scenic view but also faces the afternoon sun, leading to increased heat inside the house. The window measures 2.5 m by 2 m, and the temperature difference between the outside and the inside during a sunny afternoon is 20°C. The overall heat transfer coefficient (U-value) of the window is 1.1 $W/m^2 \cdot °C$. Calculate the heat gain through the wind

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KNOWLEDGE REVIEW

A refrigerator is working to keep the food inside at a steady temperature. The coolant inside the refrigerator absorbs heat at a rate of 0.8 kg/s, and the temperature difference between the absorption and release points is 15°C. The specific heat capacity of the coolant is approximately 4.2 kJ/kg·°C. Calculate the refrigeration load of the system.

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Thank You!