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Mitigation Enabling Energy Transition in the MEDiterranean region

THERMAL PERFORMANCE OF BUILDING ENVELOPE – E1

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OUTLINE

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What is Building Envelope and its Thermal Performance?

- **The building envelope (or the more modern term, building enclosure) is all of the elements of the outer shell that maintain a dry, heated, or cooled indoor environment and facilitate its climate control.**

Building envelope design is a specialized area of architectural and engineering practice that draws from all areas of building science and indoor climate control. It is the structural barrier between the interior and exterior of a building. It is responsible for maintaining climate control within the interior of a building. Climate control refers to cooling and heating a building. The building envelope also keeps the interior free from moisture, sound, and light. The building envelope structure includes the: Roof, Walls, Foundation, Doors, and Windows.

What is Building Envelope and its Thermal Performance?

- In the era of raising environmental problems, built structures are considered as one of the main energy consuming entities which are ultimately responsible for environmental degradation. To handle the issue, it is important to deal with buildings energy demand which is mainly due to extreme weather conditions. Because it's directly exposed to the outdoor environment, how the building envelope copes with the weather plays a major role in deciding building's energy demand.

This chapter deals with the improvement of thermal performance of Building Envelope in relation to climate, indices and local solar time of region. It also focuses on new facades technologies which lower down the building's energy demand with better insulation. To achieve this goal an integrated approach is required which comprises techniques, technologies, architectural innovation all together. These facades also have benefits other than energy saving. Numerous technologies are being developed to generate energy also.

How does the Building Envelope affect the Heating and Cooling Energy Needs?

- In the winter, the building envelope helps prevent the transfer of heat from inside to outdoors. Similarly, during the summer months, the envelope keeps the cooled air inside and the hot air outside.

- Because of this barrier, the building envelope plays a key role in a structure's energy efficiency. Keeping heated or cooled air inside (and their respective opposites out) means less energy used and less money spent on heating and cooling.

- Building envelope technologies account for approximately 30% of the primary energy consumed in residential and commercial buildings; these technologies affect many factors related to a building's energy consumption, including lighting, ventilation, and the energy required to heat and cool the building.

How does the Building Envelope affect the Heating and Cooling Energy Needs?

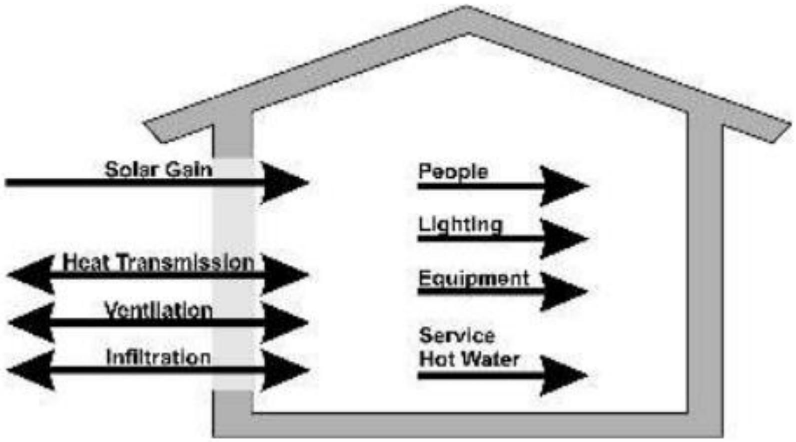
A building envelope is everything that separates the internal building from the external environment, including the roof, doors, windows, floors, and walls. Good insulation in the walls, high-efficiency windows, and sufficiently sealed gaps increase the effectiveness of the envelope.

Building thermal performance enhancement is a topical issue of construction and architecture. The evaluation of building thermal performance can be carried out in various ways: to describe the thermal performance of the building envelope and its components we use a variation of metrics; such as, R-value, ACH (air exchange rate per hour), SHGC (solar heat gain coefficient) of windows, U-factor etc.

How does the Building Envelope affect the Heating and Cooling Energy Needs?

- Heat transfer from outside to inside takes place through the Building Envelope and the quantities are derived through certain basic principles.

Because the building envelope can significantly affect the amount of required lighting and HVAC—the two largest end uses of energy in both the residential and commercial sectors, improvements to the building envelope have the potential to reduce GHG emissions from new and existing buildings in the residential and commercial buildings. In addition, building envelope improvements also result in a variety of benefits for occupants, including lower energy bills, as well as improved thermal comfort, moisture control, and noise control.



Climate

- **As climate plays a vital role in building energy performance, Design Strategies for high performance facades in Hot & Humid regions are quite different from those in Hot & Arid regions.**

Cold Climate Design Strategies:

- Collection of Solar energy & Passive heating collection of solar heat through building envelope.
- Daylight Use of natural light & glazing area of facades can be increased. High performance glass can be used. Light shelves can be used to allow the light into interior spaces.
- Heat Conservation through improved insulation heat can be preserved into building.

Climate

Hot Climate Design Strategies:

- Solar Control External façade of building can be protected through use of self-shading methods (building form) or by using shading devices.
- Reduced external Solar heat-gains through infiltration can be protected by use of well insulated opaque façade elements. Also, solar heat- gains through conduction can be protected by use of shading devices.
- Cooling Natural ventilation can be used for cooling of building where environmental characteristics and buildings functions allow.
- Daylight by use of shading devices and lighting shelves; natural light can be used for interior spaces with minimum solar heat-gains.

Climate

Mixed Climate Design Strategies:

- Solar Control external facades can be protected from direct solar radiation through shading devices during warm seasons.
- Solar collection & passive heating Solar energy can be collected in cold seasons
- Daylight Use of natural light sources and increased glazed façade with use of shading devices.

Building Facades

Building Façades affects buildings energy bills and occupants' health more than any other system. Heat transfers into buildings through conduction, convection & radiation. Heat transfer through conduction depends on conductivity of materials used in exterior facades. Different materials have different conductivity so they offer different resistance to conductive heat. Walls and roofs generally comprise numerous of layers composed of different materials so it is very important to know their overall thermal resistance and heat transfer coefficient (U-factor). Heat transfer coefficient is also known as thermal transmittance or thermal transmission through the unit area of a building unit divided by temperature difference between the air on either side of the building unit. U Value is the basic essential quantification measure for every climate but not just the one through which thermal efficiency is obtained.

Building Facades

- Heat transfer is the transition of thermal energy from a heated space to a cooler area. There are three means of heat transfer that need to be considered when planning to make a building energy efficient:

Conduction – Transfer of heat through matter from a higher temperature region to a lower temperature region.

Convection – Transfer of heat occurring because of the movement of fluids and gases (e.g., air moving in a wall cavity).

Radiation – Electromagnetic radiation emitted from the surface of an object (e.g., radiation emitted from an aluminum foil).

Orientation of Building

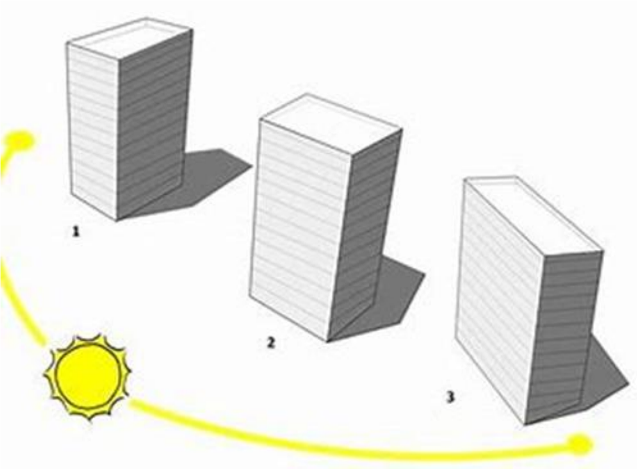
Orientation, geometry and massing of building should respond to sun position. Building Orientation determines its sun exposure. Sun rises in the east & sets in the west only on autumnal & vernal equinoxes. For rest of remaining 363 days, it rises and sets differently. As earth is tilted, it pushes the sunrise and sunset slightly south of east & west in the winter and slightly north of east & west in the summer. This slight angle depends on the time of year and distance of the observer from the equator. Therefore, an optimal orientation can maximize solar heat gain in winter and avoid direct solar radiation into interior spaces during summer. Building orientation should be an essential part of your building design. You can get the benefits of natural light and maximum ventilation in all seasons and climate conditions. The right building orientation ensures comfort within the building, and it can make you save a lot on energy bills. The orientation of a building can also protect from the negative effects of inclement weather.

Solar and wind orientation are the two main factors which need to be taken into consideration when you are constructing a new building.

Orientation of Building

Solar temperature and radiation

The solar radiation intensity is dependent on the direction of the sun's rays. A building's temperature and the interior temperature increases or decreases according to sun radiation. This radiation acts in two different ways – The sunrays enter a building through various openings and radiation comes in indirectly through roofs and walls of a building by absorbing the heat of the sun



For a comfortable occupancy of a building, the best orientation is the one which gets maximum sunlight during winter and minimum sunlight during summer. If it's a cold climate, there should be more openings in the Southern side of the building, which can be closed off by curtains or other closures that cut off the direct rays of the sun during summer. The opposite should be done in hot climates, as the building should have less solar radiation during summer.

Orientation of Building

Solar temperature and radiation

Solar heat which is reflected from the ground can be minimized by **growing a grassy patch** in the front of the south façade (Refer to GS). Both the western and eastern facades receive equal amount of light. But when the sun is shining on the western side of the building in the afternoon, the temperature is higher, so you have to get **openings** constructed on the western façade for **more ventilation** to reduce the heat (Refer to EDE4A).

Orientation of Building

Wind orientation

The wind direction and velocity should be studied at your site for the whole of the year. The building should be oriented in such manner that the wind flow should be more in the building during the humid season than in other seasons. The prevailing winds at your location can create natural ventilation, especially in highly humid conditions. The windows and doors should be at the proper locations to provide maximum advantage due to wind.

Orientation of Building

Rains and clouds

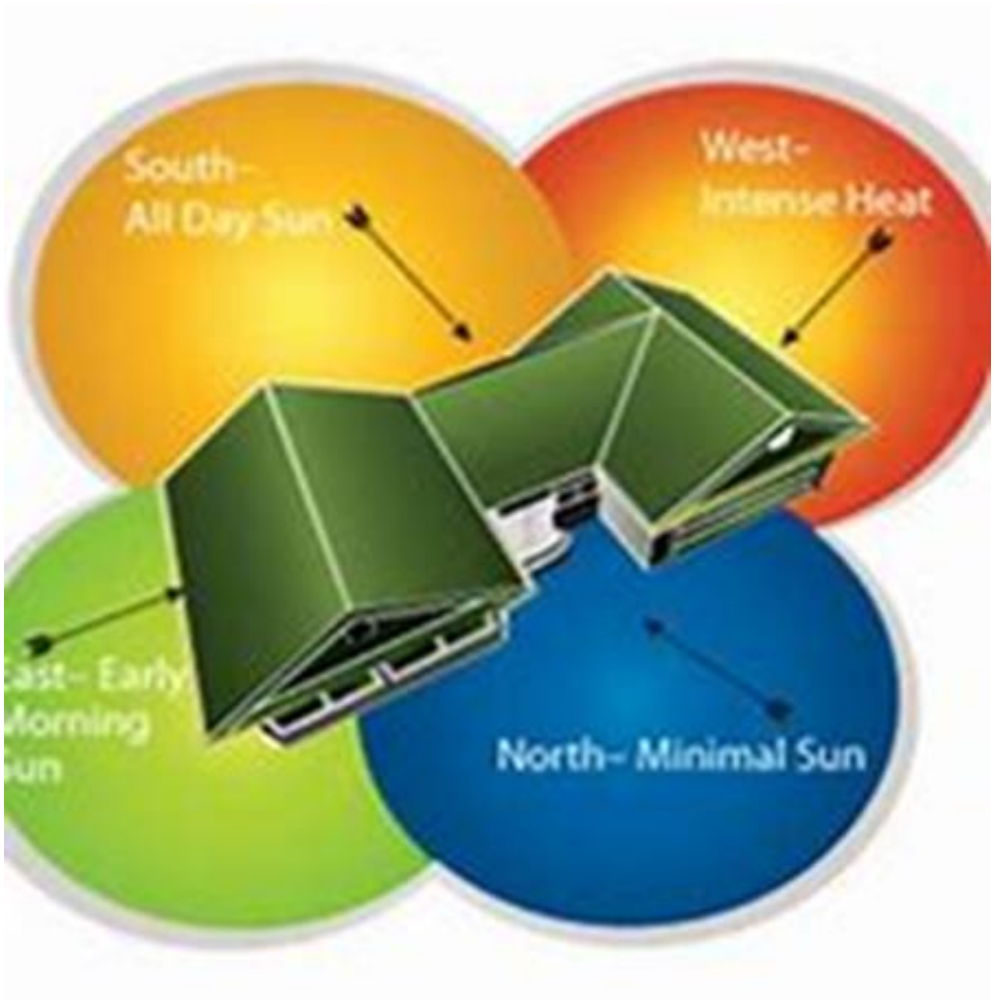
Rains and clouds have lower importance while planning building orientation. The openings and glazing should be planned according to the rain direction, as the rain direction is same as the wind's direction during storms. If your architect does design glazing for your building, then you should cover it with a sunshade. Thinner walls of the building should not be oriented towards heavy rain direction.

Orientation of Building

Humidity

Humidity does not affect the orientation of a building directly, but properly planning according to wind orientation, which will ventilate your home naturally, will give you relief from humid heat, even when there is little natural breeze.

Orientation of Building Benefit



The main benefit of building orientation is in energy efficiency. It reduces the heating, lighting and cooling costs of the building by coping efficiently with natural light, winds and sun so that occupants can enjoy the warmth of the sun in winter, and cool breezes during summer.

Windows

Windows serve as a main point of entry for air leaks and are often overlooked in terms of their abilities to act as a barrier in a building envelope. Triple pane windows are frequently used in colder climates to prevent wind or snow from entering the home. Double pane windows are considered equally effective in more moderate temperature climates. Windows are given an efficiency rating known as a U-value with lower numbers being more efficient than higher values.

A similar dynamic system is used to rank insulation which is done using an R-value. This number describes the ability of insulative material to resist the flow of heat through it. In more scientific terms, the R-value is known as the thermal resistance of a material and is inversely correlated to the thermal conductivity a material expresses. Unlike U-values, the higher the R-value a material possesses, the more efficient it is at resisting heat transfer.

Natural ventilation

Natural ventilation for enhanced air quality and reduced cooling loads (Refer to EDE4A).

Solar shading devices and Daylighting

Provision of solar shading devices to control cooling loads and to improve thermal comfort (Refer to EDE3).

Thermal Properties of a Building Envelope

The thermal properties of a building material are accessed primarily through determining the thermal conductivity of its components which directly corresponds to the ability of a material to effectively allow heat to pass through it. Materials with a high thermal conductivity value will promote heat transfer and allow heat to quickly pass through them. Ideally, a building envelope should be primarily composed of materials with extremely low thermal conductivity values and incorporate additional materials that act strictly as thermal insulators that further block the movement of heat from the inside of a structure to the outside and vice versa. Building designers are urged to select the correct combination of materials to regulate heat movement naturally without the need for expensive mechanical heating and cooling systems. All of the components they select will interact as a unit to perform four crucial functions: structural support, moisture management, temperature regulation, and airflow regulation. The latter three have the most pronounced influence on ensuring that a house is energy efficient, comfortable, and sustainable.

Why does a Thermal Envelope matter?

Like other industries, the world of construction and HVAC have their terminology for concepts that insiders understand, but the general public may not. A thermal envelope is one of these terms. Put simply, every home has a thermal envelope. It's the structure that separates the air inside your home from the air outside. This includes things like: Windows, Floors, Exterior walls, Outer doors, Insulation, Air/vapor retarders, Weatherstripping, and Caulking. A thermal envelope serves three distinct functions:

Air control – Managing air movement within your living spaces is important for managing energy consumption, preventing condensation from accruing, ensuring that air quality is optimal, and making the space comfortable. This air control includes both movements through the home's enclosure and the heat flow control layer. A drafty house, for instance, has poor air control

Moisture control – Moisture can threaten the structure's integrity and wreak havoc on the interior thanks to mold and other issues. Left unchecked, it can cause damage to the foundations of the home. As such, an envelope's ability to control and minimize moisture is one of its most critical tasks, especially in hot-humid climates or those that experience snowy winters.

Thermal control – As the name suggests, a thermal envelope makes it easier to reach and then maintain your ideal temperature no matter the time of the year. If you're feeling too hot in the summer or too cold in the winter, it may be time to look for ways to increase your building envelope's efficacy.

Objectives

The intent of this measure is to improve the thermal performance of building envelope for both residential and commercial buildings, which will improve the thermal comfort inside the building leading to the reduction in energy needs for space heating and cooling.

Earned Credit:

With GRASSMED, Thermal performance is evaluated based on:

E1-1: Thermal Transmittance U-value of the Envelope – U env

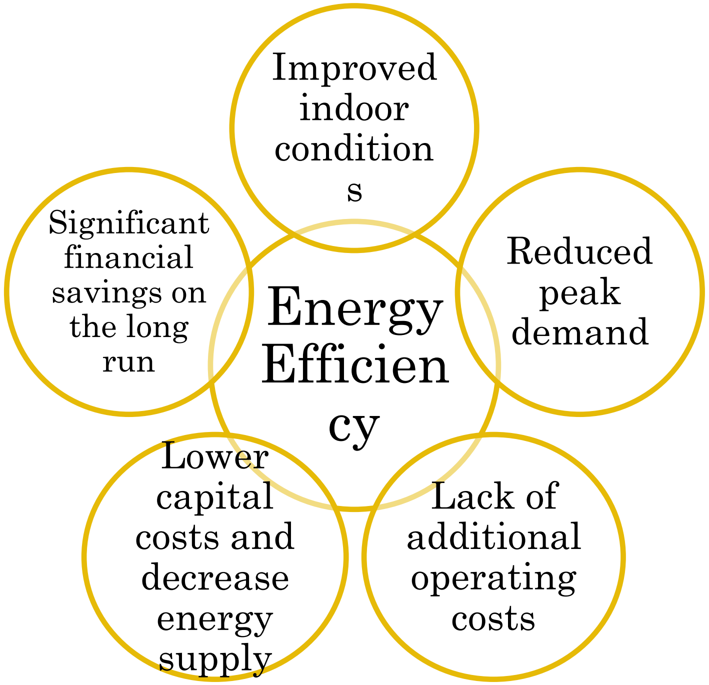
E1-2: Thermal Transmittance of the Building façade - UFACADE

E1-3: Window to Wall Ratio WWR eq

E1-4: Slab on the ground Thermal Resistance

Energy Efficiency of Building Envelope : Heat Gains and Losses Calculation

Introduction to Energy Efficiency: Why is it important in buildings?

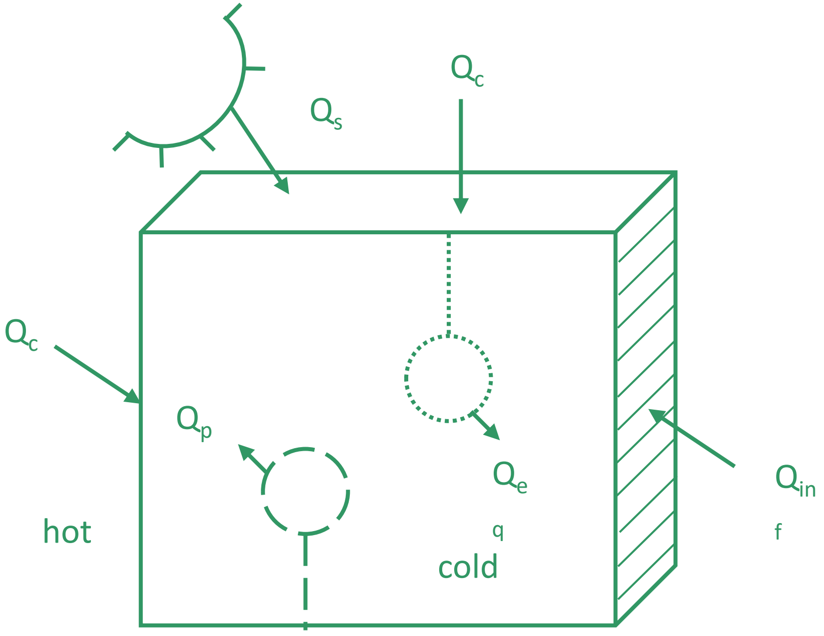


Components of Energy Efficiency in Buildings

Envelope	• Walls, doors, windows and roofs
Lighting System	• Lamps, ballasts, controlling devices, and luminaires.
Equipment	• Cooling equipment (chillers or split units), heating equipment (boilers, radiators), refrigerators, printers, etc.
Hot Water Supply	• Hot water tank, pipes, heat source

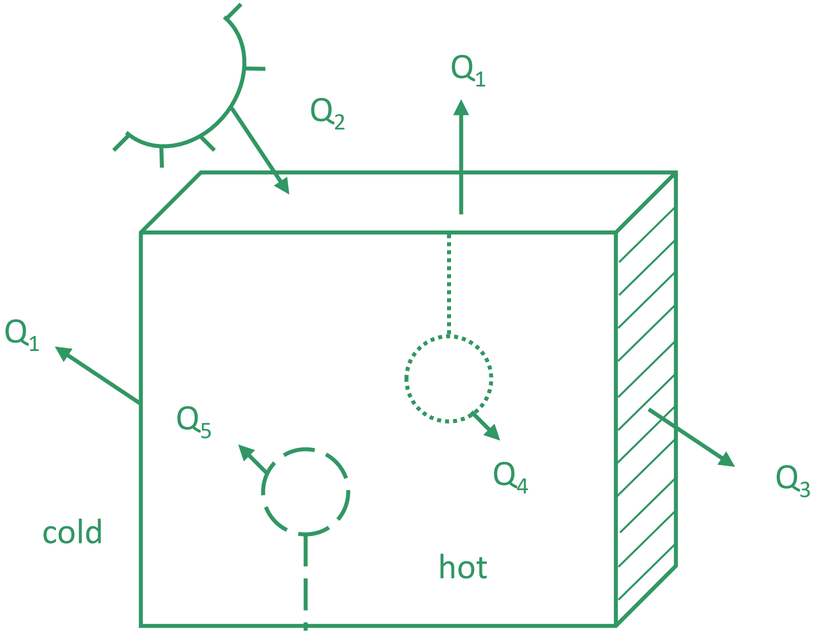
Heat Gain in a Building

- $Q_{in}=Q_c+Q_s+Q_{inf}+Q_{eq}+Q_p$
- Where
- Q_c: Heat conducted through the building's envelope.
- Q_s: Heat gained by solar radiation.
- Q_{inf}: Heat gained by infiltration and air renewal.
- Q_{eq}: Heat emitted by equipment.
- Q_p: Heat emitted by people.



Heat Loss in a Building

- $Q_{out}=Q_c-Q_s+Q_{inf}-Q_{eq}-Q_p$
- Where
- Q_c: Heat loss conducted through the building's envelope.
- Q_s: Heat gained by solar radiation.
- Q_{inf}: Heat loss by infiltration and air renewal.
- Q_{eq}: Heat emitted by equipment.
- Q_p: Heat emitted by people.



Heat Transfer in a Building: Conduction

Thermal Transmittance (U-value):

- It is the heat flow rate in the steady state divided by the area and the temperature difference between the boundaries of a solid body.
- Unit $[W/m^2K]$

Thermal Resistance (R-value):

- It is a heat property that measures the temperature difference by which an object resists heat flow. Unit $[K/W]$
- It is a heat property that measures the temperature difference by which the area of an object resists heat flow. Unit $[K.m^2/W]$

Heat Transfer in a Building: Thermal Resistance-Conduction

- Conduction

$$R_{cond} = \frac{L}{k \times A} \text{ in K/W}$$

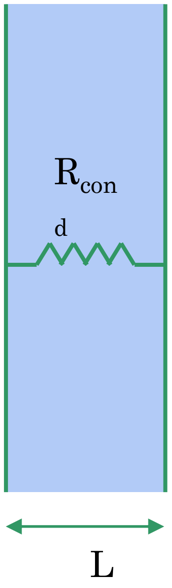
Where

- L: distance between the hot and the cold surface in m
- k: the thermal conductivity of the material enclosed between both surfaces in W/m.K
- A: wall's area in m2

Or $$R_{cond} = \frac{L}{k} \text{ in K.m}^2\text{/W}$$

Where

- L: distance between the hot and the cold surface
- k: the thermal conductivity of the material enclosed between both surfaces in W/m.K



Heat Transfer in a Building: Combined Thermal Resistance

- Combined Thermal Resistance: (convection + radiation)

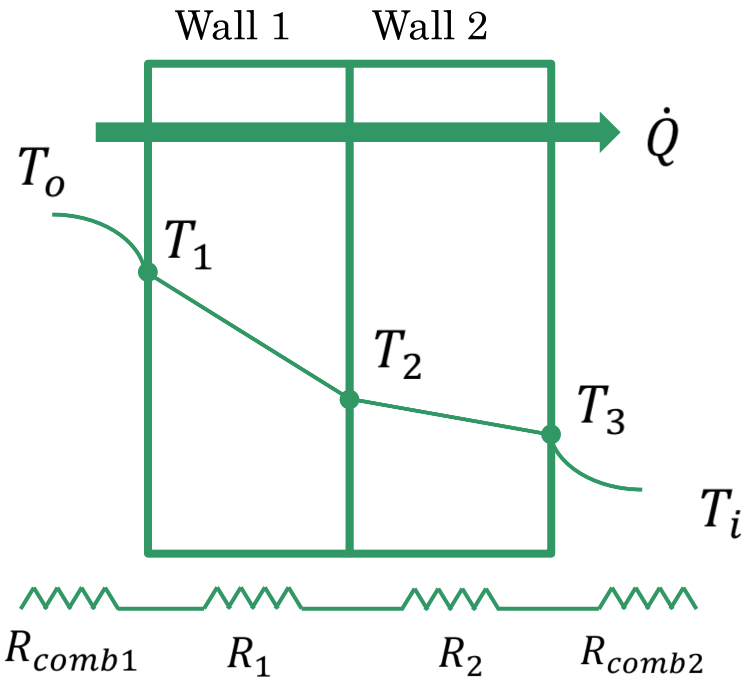
$$h_{comb} = h_{conv} + h_{rad}$$

$$R_{comb} = \frac{1}{h_{comb} \times A}$$

- h_{comb} is typically reported in studies.

Heat Transfer in a Building: Thermal Transmittance of a Wall

- $R_t = R_{comb1} + R_1 + R_2 + R_{comb2}$
  - $R_{comb1} = \frac{1}{h_{comb1} \times A} = \frac{1}{(h_{conv1} + h_{rad1}) \times A}$
  - $R_1 = \frac{L_1}{k_1 \times A}$
  - $R_2 = \frac{L_2}{k_2 \times A}$
  - $R_{comb1} = \frac{1}{(h_{comb2}) \times A} = \frac{1}{(h_{conv2} + h_{rad2}) \times A}$
- $U_t \times A = \frac{1}{R_t} = \frac{1}{\frac{1}{h_{comb1} \times A} + \frac{L_1}{k_1 \times A} + \frac{L_2}{k_2 \times A} + \frac{1}{h_{comb2} \times A}}$



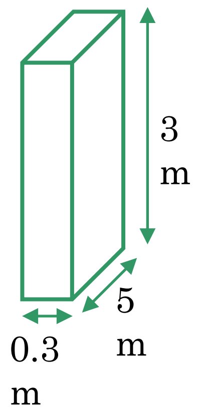
Heat Transfer in a Building: Thermal Transmittance of a Wall

- Example: Consider a wall whose width (W) is 5m, height (H) is 3m and thickness (L) is 0.3m. The conductivity of the wall's material (k) is 0.9 W/mK. The combined heat transfer coefficients at the inner and outer sides of the wall are 10 W/m^2K and 40 W/m^2K respectively.

a. Calculate the overall thermal transmittance of the wall (U_{ta}).

b. A polystyrene layer, having a thickness of 5cm and a thermal conductivity of 0.03 W/mK, is added to the wall. Calculate the new thermal transmittance of the wall (U_{tb}).

c. How much should the thickness of the wall be in case no additional layer of polystyrene is added but the overall transmittance of the wall is equal to the value calculated in part b.



Heat Transfer in a Building: Thermal Transmittance of a Wall

- Given:
- W=5m, H=3m, L=0.3m
- h_{comb1} = 40 W/m²K
- h_{comb2} = 10 W/m²K

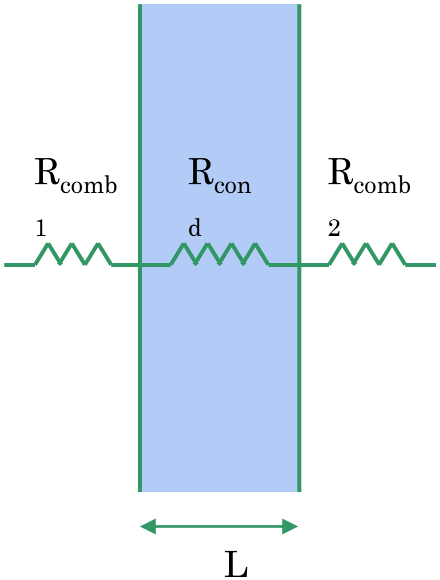
Solution:

a. Wall's area=3×5=15m²

$$R_{comb1}=\frac{1}{h_{comb1}\times A}=\frac{1}{40\times15}=0.00167\frac{K}{W}$$

$$R_{comb2}=\frac{1}{h_{comb2}\times A}=\frac{1}{10\times15}=0.00667\frac{K}{W}$$

$$R_{cond}=\frac{L}{K\times A}=\frac{0.3}{0.9\times15}=0.022\frac{K}{W}$$



Heat Transfer in a Building: Thermal Transmittance of a Wall

a. Total thermal resistance

$$R_{ta}=R_{comb1}+R_{cond}+R_{comb2}$$

$$R_{ta}=0.00167+0.022+0.00667$$

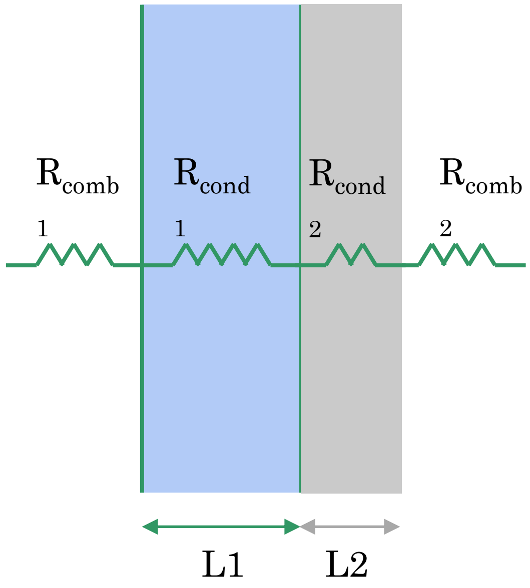
$$R_{ta}=0.03034\frac{K}{W}$$

$$U_{ta}=\frac{1}{R_{ta}A}=\frac{1}{0.03034\times 15}\approx 2.2\frac{W}{m^2K}$$

b. Polystyrene Layer

$$R_{tb}=R_{comb1}+R_{cond1}+R_{cond2}+R_{comb2}$$

$$R_{cond2}=\frac{L_2}{k_2A}=\frac{0.05}{0.03\times 15}=0.11\frac{K}{W}$$



Heat Transfer in a Building: Thermal Transmittance of a Wall

b. Polystyrene Layer

$$R_{tb}=R_{comb1}+R_{cond1}+R_{cond2}+R_{comb2}$$

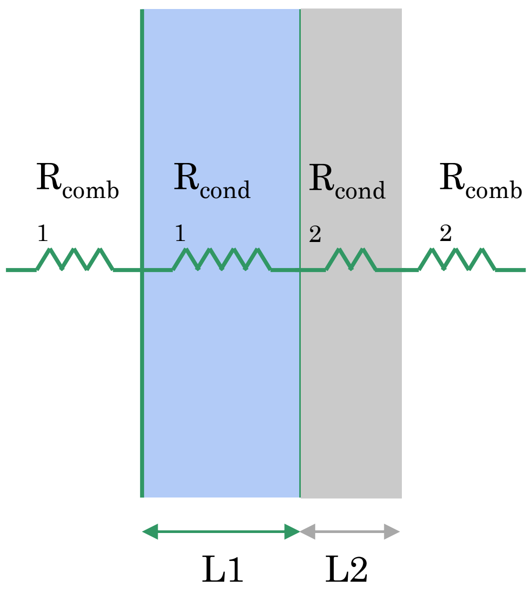
$$R_{cond2}=\frac{L_2}{k_2A}=\frac{0.05}{0.03\times 15}=0.11\,\frac{K}{W}$$

$$R_{tb}= 0.00167 + 0.022 + 0.11 + 0.00667 = 0.14034\,\frac{K}{W}$$

$$U_{tb}=\frac{1}{R_{tb}A}=\frac{1}{0.14034\times 15}=0.475\,\frac{W}{m^2K}$$

$$\%\text{ decrease in } U_t=\frac{U_{ta}-U_{tb}}{U_{ta}}\times 100=\frac{2.2-0.475}{2.2}\times 100$$

$$\%\text{ decrease in } U_t = 78\ \%$$



Heat Transfer in a Building: Thermal Transmittance of a Wall

c. Wall thickness for an equivalent U-value

$$R_{tb}=\frac{1}{U_{tb}A}=\frac{1}{0.475\times 15}=0.1403$$

$$R_{tb}=R_{comb1}+R_{cond1}+R_{cond2}+R_{comb2}$$

$$0.1403=0.00167+0.022+R_{cond2}+0.00667$$

$$R_{cond2}=\frac{L_2}{k_2A}=0.11\,\frac{K}{W}$$

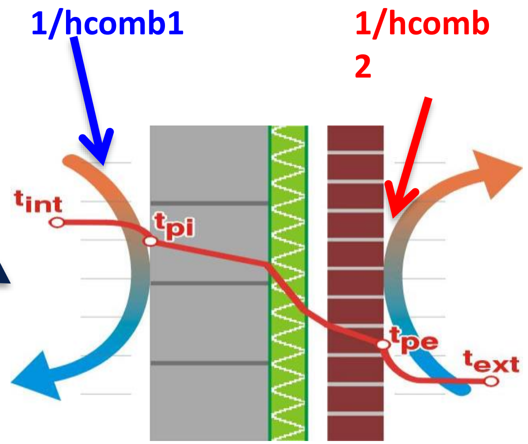
$$L_2=k_2AR_{cond2}=0.9\times 15\times 0.11\approx 1.485\ \text{m}$$

Heat Transfer in a Building: Thermal Transmittance of a Wall

Parameter	Symbol	Definition	Unit
Thermal Transmittance	U	Heat flow rate in steady state divided by the area and the temperature difference between the surroundings on each side of a system.	W/m².K

In case all layers have the same area we can use this formula :

$$U = \frac{1}{\frac{1}{h_i} + \sum \frac{e}{\lambda} + Ra + \frac{1}{h_e}}$$



Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

- Building's Envelope = Roof + Exposed Walls + Doors + Windows+ Skylights + Exposed Floors/Semi-exposed Floors
- To calculate the U-value of the entire envelope, we should do the following:
  - Calculate the area of each component
  - Calculate the U-value of each component
  - Apply the following equation

$$U_{env} = \frac{\sum(U_i \times A_i)}{A}$$

Where:

- U_i is the overall thermal transmittance of a component
- A_i is the area of a component
- U_{env} is the overall thermal transmittance of the envelope
- A is the total area of the envelope

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

- Consider a 4-storey building whose length, width and height are 20m, 15m and 16m respectively. The ground floor of this building is exposed to an underground parking lot and thus it is considered a semi-exposed floor.
- The length and height of the northern and southern façades are 15x16m respectively. The length and height of the eastern and western facades are 20mx16m respectively.
- Each floor has two single pane windows on the northern façade and two single pane windows on the eastern façade. The overall transmittance of each window is provided by the manufacturer, and it is equal to 5.8 $\frac{\mathrm{W}}{\mathrm{m^2K}}$.
- The windows on the northern façade have the following dimensions 2mx2m, and those on the eastern façade are have the following dimensions 3mx3m.
- The material of construction of the walls, roof and semi-exposed floor are presented in the following slide.
- The inner and outer combined heat transfer coefficients are 9.1 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ and 16.7 $\frac{\mathrm{W}}{\mathrm{m^2K}}$ respectively.

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Exposed Wall's Layers	Thermal Conductivity (W/mK)	Thickness (mm)
Plaster	0.72	10
Hollow Block	0.56	150
Plaster	0.72	10

Semi-exposed floor	Thermal Conductivity (W/mK)	Thickness (mm)
Tile	0.34	30
Mortar	0.714	10
Sand	0.869	60
Slab	1.82	80
Hollow Block	0.56	120
Plaster	0.72	10

Roof's Layers	Thermal Conductivity (W/mK)	Thickness (mm)
Sand	0.85	100
Weatherization	0.17	10
Concrete	1.77	200
Plaster	0.72	10

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

- Step 1: Calculate the area of each component
- Areas of facades
  - $A_F = L \times H$ (F: Façade)
  - $A_{EF} = A_{WF} = 20 \times 16 = 320\ m^2$ (EF: Eastern Façade – WF: Western Façade)
  - $A_{NF} = A_{SF} = 15 \times 16 = 240\ m^2$ (NF: Northern Façade – SF: Southern Façade)
  - $A_R = A_B = L \times W = 20 \times 15 = 30\ m^2$ (R: Roof – B: Basement)
- Areas of windows
  - $A_{Wn} = \left(\frac{\#\ \text{of windows}}{\text{floor}} \times \#\ \text{of floors} \times \text{Area of one window}\right)$
  - $A_{EWn} = 2 \times 4 \times 9 = 72\ m^2$ (EWn: windows on Eastern Façade)
  - $A_{NWn} = 2 \times 4 \times 4 = 32\ m^2$ (NWn: windows on Northern Façade)
  - $A_{WWn} = A_{SWn} = 0\ m^2$
- Areas of walls
  - $A_{Wl} = A_F - A_{Wn}$
  - $A_{EWl} = A_{EF} - A_{EWn} = 320 - 72 = 248\ m^2$ (NWl: wall on Northern Façade)
  - $A_{WWl} = 320\ m^2$
  - $A_{NWn} = A_{NF} - A_{NWn} = 240 - 32 = 208\ m^2$ (Ewn: wall on Eastern Façade)
  - $A_{SWl} = 240\ m^2$

Areas of Facades	
East (A_{EF})	320 m^2
West (A_{WF})	320 m^2
North (A_{NF})	240 m^2
South (A_{SF})	240 m^2
Areas of Windows	
East (A_{EWn})	72 m^2
West (A_{WWn})	0 m^2
North (A_{NWn})	32 m^2
South (A_{SWn})	0 m^2
Areas of Walls	
East (A_{EWl})	248 m^2
West (A_{WWl})	320 m^2
North (A_{NWl})	208 m^2
South (A_{SWl})	240 m^2

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Exposed Wall's Layers	Thermal Conductivity (W/mK)	Thickness (mm)
Plaster	0.72	10
Hollow Block	0.56	150
Plaster	0.72	10

$$R_{wall} = R_{comb1} + R_{p1} + R_{HB} + R_{p2} + R_{comb2}$$

$$R_{wall} = \frac{1}{h_{comb1} \times A_{wall}} + \frac{L_{p1}}{k_{p1} \times A_{wall}} + \frac{L_{HB}}{k_{HB} \times A_{wall}} \frac{L_{p1}}{k_{p1} \times A_{wall}} + \frac{1}{h_{comb2} \times A_{wall}}$$

$$R_{wall} = \frac{1}{A_{wall}}\left(\frac{1}{h_{comb1}} + \frac{L_{p1}}{k_{p1}} + \frac{L_{HB}}{k_{HB}} + \frac{L_{p2}}{k_{p2}} + \frac{1}{h_{comb2}}\right)$$

$$R_{wall} = \frac{1}{A_{wall}}\left(\frac{1}{9.1} + \frac{0.01}{0.72} + \frac{0.15}{0.56} + \frac{0.01}{0.72} + \frac{1}{16.7}\right)$$

$$R_{wall} = \frac{0.465}{A_{wall}}$$

$$U_{wall} = \frac{1}{R_{wall}A_{wall}}$$

Wall's Thermal Resistance	
East (R_{EWl})	$0.0019\ \frac{K}{W}$
West (R_{WWl})	$0.0015\ \frac{K}{W}$
North (R_{NWl})	$0.002\ \frac{K}{W}$
South (R_{SWl})	$0.0019\ \frac{K}{W}$

Wall's Thermal Transmittance	
East (U_{EWl})	$2.12\ \frac{W}{m^2K}$
West (U_{WWl})	$2.08\ \frac{W}{m^2K}$
North (U_{NWl})	$2.4\ \frac{W}{m^2K}$
South (U_{SWl})	$2.19\ \frac{W}{m^2K}$

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Roof's Layers	Thermal Conductivity (W/mK)	Thickness (mm)
Sand	0.85	100
Weatherization	0.17	10
Concrete	1.77	200
Plaster	0.72	10

$$R_{roof} = R_{comb1} + R_s + R_w + R_c + R_p + R_{comb2}$$

$$R_{roof} = \frac{1}{h_{comb1} \times A_{roof}} + \frac{L_s}{k_s \times A_{roof}} + \frac{L_w}{k_w \times A_{roof}} + \frac{L_c}{k_c \times A_{roof}} + \frac{L_p}{k_p \times A_{roof}} + \frac{1}{h_{comb2} \times A_{roof}}$$

$$R_{roof} = \frac{1}{A_{roof}} \left(\frac{1}{h_{comb1}} + \frac{L_s}{k_s} + \frac{L_w}{k_w} + \frac{L_c}{k_c} + \frac{L_p}{k_p} + \frac{1}{h_{comb2}} \right)$$

$$R_{roof} = \frac{1}{A_{roof}} \left(\frac{1}{9.1} + \frac{0.1}{0.85} + \frac{0.01}{0.17} + \frac{0.2}{1.77} + \frac{0.01}{0.72} + \frac{1}{16.7} \right)$$

$$R_{roof} = \frac{0.4732}{A_{roof}} = \frac{0.4732}{300} = 0.0016 \frac{K}{W}$$

$$U_{roof} = \frac{1}{R_{roof} \times A_{roof}} = \frac{1}{0.0016 \times 300} = 2.083 \frac{W}{m^2 K}$$

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Semi-exposed floor	Thermal Conductivity (W/mK)	Thickness (mm)
Tile	0.34	30
Mortar	0.714	10
Sand	0.869	60
Slab	1.82	80
Concrete hollow block	0.56	120
Plaster	0.72	10

$$R_{floor} = R_{comb1} + R_t + R_m + R_s + R_{sl} + R_{hb} + R_p + R_{comb1}$$

$$R_{floor} = \frac{1}{A_{floor}}\left(\frac{1}{h_{comb1}} + \frac{L_t}{k_t} + \frac{L_m}{k_m} + \frac{L_s}{k_s} + \frac{L_{sl}}{k_{sl}} + \frac{L_{hb}}{k_{hb}} + \frac{L_p}{k_p} + \frac{1}{h_{comb1}}\right)$$

$$R_{floor} = \frac{1}{A_{floor}}\left(\frac{1}{9.1} + \frac{0.03}{0.34} + \frac{0.01}{0.714} + \frac{0.06}{0.869} + \frac{0.08}{1.82} + \frac{0.12}{0.56} + \frac{0.01}{0.72} + \frac{1}{9.1}\right)$$

$$R_{floor} = \frac{0.663}{A_{floor}} = \frac{0.663}{300} = 0.00221\,\frac{K}{W}$$

$$U_{floor} = \frac{1}{R_{floor} \times A_{floor}} = \frac{1}{0.00221 \times 300} = 1.51\,\frac{W}{m^2K}$$

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Component	U-value $\frac{W}{m^2K}$	Area (m^2)	$U \times A$
Windows East	5.8	72	417.6
Windows North	5.8	32	185.6
Wall East	2.12	248	525.76
Wall West	2.08	320	665.6
Wall North	2.4	208	499.2
Wall South	2.19	240	525.6
Roof	2.08	300	624
Floor	1.51	300	453
Total		1720	3896
$U_{env}\left(\frac{W}{m^2K}\right)$			2.26

Heat Transfer in a Building: Energy Consumption due to Conduction

- Heating Degree Days (HDD)

$$HDD = \sum_{i=1}^{N_H} T_b - T_o$$

- Cooling Degree Days (CDD)

$$CDD = \sum_{i=1}^{N_C} T_o - T_b$$

  - T_b: Indoor temperature of the building (°C or K)
  - T_o: Outdoor temperature (°C or K)
  - N_H: Number of heating days (days)
  - N_C: Number of cooling days (days)

Heat Transfer in a Building: Energy Consumption due to Conduction

- Annual Heating Load

$$Q_H = U_{env} \times A_{env} \times \Delta T \times t$$

  - U_{env} is the overall thermal transmittance of the envelope $(\frac{W}{m^2K})$
  - A_{env} is the total area of the envelope (m^2)
  - ΔT is the temperature difference between the interior of the building and its average exterior (K) for the period.
  - t is the time (hr)

$$Q_H = U_{env} \times A_{env} \times \Delta T \times N_H \times 24$$

  - N_H is the number of heating days (day)

$$Q_H = U_{env} \times A_{env} \times HDD \times 24$$

  - HDD is the heating degree days (K.day)
- Annual Cooling Load

$$Q_C = U_{env} \times A_{env} \times CDD \times 24$$

Heat Transfer in a Building: Energy Consumption due to Conduction

	$T_b = 15.6\ ^\circ C$	$T_b = 18.3\ ^\circ C$	$T_b = 21.1\ ^\circ C$
CDD	590	368	211
HDD	3206	3970	4836

We will assume that the building's temperature is maintained at 18.3 °C. Hence, CDD = 368 K.days and HDD = 3970 K.days.

Parameter	Value
$U_{env}\left(\frac{W}{m^2K}\right)$	2.26
A_{env} (m^2)	1720
HDD (K.day)	3970
CDD (K.day)	368
Q_H (MWh)	370.4
Q_C (MWh)	34.33

Heat Transfer in a Building: Energy Consumption due to Conduction

	$T_b = 15.6$ ˚C	$T_b = 18.3$ ˚C	$T_b = 21.1$ ˚C
CDD		522	
HDD		1820	

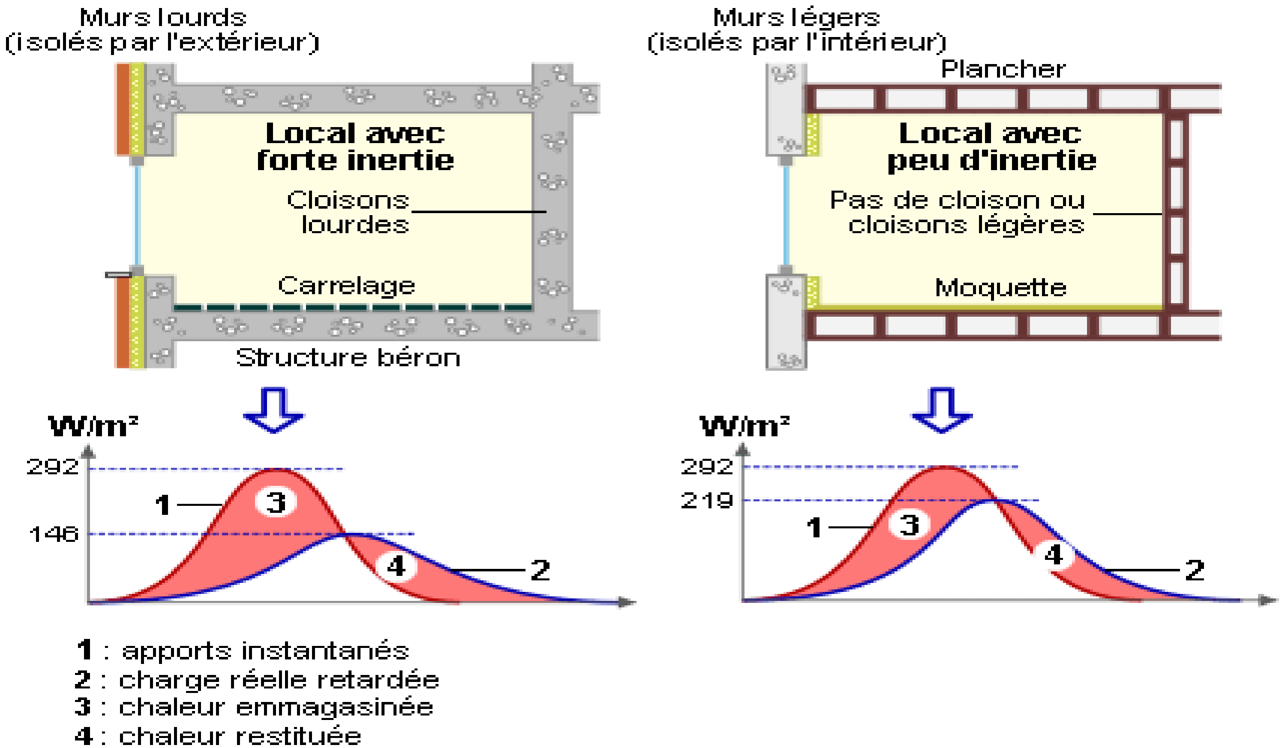
We will assume that the building's temperature is maintained at 18.3 ˚C. Hence, CDD = 522 K.days and HDD = 1820 K.days. The heated area is

Parameter	Value
U_{env} $\left(\frac{W}{m^2K}\right)$	2.26
A_{env} (m^2)	1720
HDD (K.day)	1820
CDD (K.day)	522
Q_H (MWh) Eh = Qh/A	169.9 147.7kwh/m2
Q_C (MWh) Ec=Qc/A	48.7 42.3Kwh/m2

Heat Transfer in a Building: How to reduce heat transfer by conduction

- Install insulation layers
- Increase the thickness of walls
- Install double pane windows

Thermal Inertia



"Thermal inertia is a key concept in the energy design of buildings. As illustrated here, buildings with high thermal inertia, thanks to massive and externally insulated materials, are capable of delaying and 'Mitigate temperature spikes. This means that during hot hours, excess heat is absorbed and stored, then it is slowly released when the temperature drops, creating a more stable and comfortable indoor environment. In contrast, buildings with little inertia, such as those with lightweight, internally insulated walls, tend to heat and cool more quickly, which can cause discomfort and require more energy to maintain a constant temperature. the design of the building envelope must take into account thermal inertia to improve energy efficiency and occupant comfort."

Heat Transfer in a Building: Infiltration

- Infiltration of air into the building results from cracks, frames of windows, frames of doors and access openings.
- As air leaks in during the winter season, it enters at a temperature lower than the interior temperature, and thus it increases the heating load.
- As air leaks in during the summer season, it carries with it heat and consequently it increases the cooling load.
- Minimizing infiltration is a desired event during both seasons since it is one method of reducing the influence of external conditions on internal ones.
- Air infiltration is more significant in small buildings than large ones

Heat Transfer in a Building: Solar Radiation

- As incident radiation strikes a surface, it could either be reflected, absorbed by the material or transmitted to the following medium.

$$G = G_\rho + G_\alpha + G_\tau$$

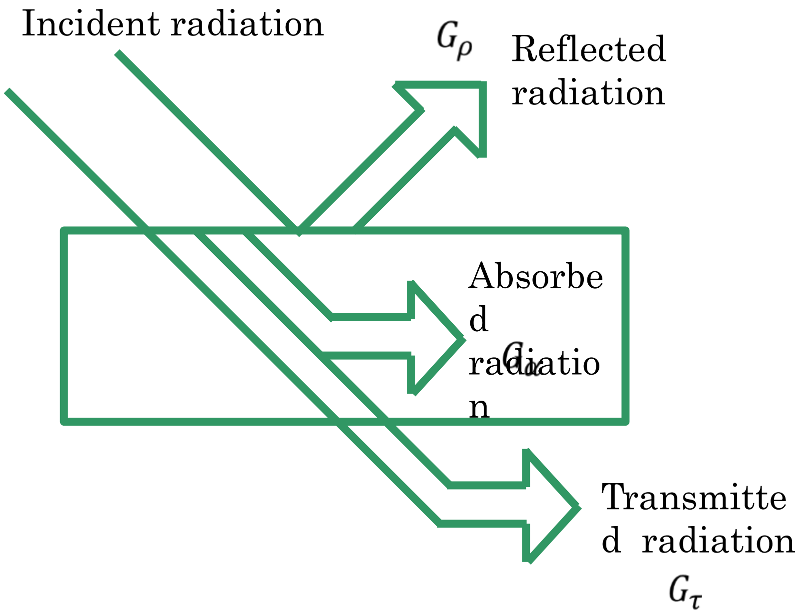
$$1 = \rho + \alpha + \tau$$

  - ρ: reflectivity
  - α: absorptivity
  - τ: transmissivity
- Opaque surfaces have a null transmissivity $\tau = 0$

$$1 = \rho + \alpha$$

- Glazing surfaces

$$1 = \rho + \alpha + \tau$$



Heat Transfer in a Building: Solar Radiation

Solar Heat Gain Coefficient

- The ratio of solar heat gain that enters the space through fenestration area to the incident radiation on that fenestration.

Architectural Shading Factor:

- It is a coefficient that takes into account the impact of external shading(fins or overhangs) on the windows' performance. It cannot exceed one which is the case in which there is no shading or shading has no effect.

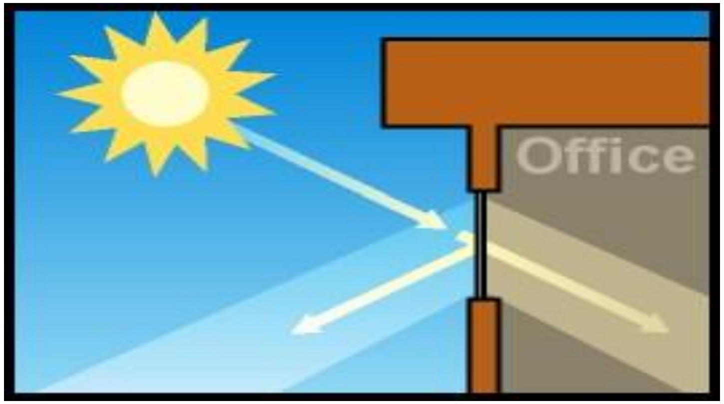
Window to Wall Equivalent Ratio

- The ratio of the total amount of solar radiation entering the building to the total solar radiation reaching the fenestration areas over an entire year.

Heat Transfer in a Building: Solar Radiation

Solar heat gain coefficient SHGC

- The glazing's effectiveness in rejecting solar heat gain
- Part of a system for rating window performance
- Gradually replacing shading coefficient (SC) in product literature and design standards

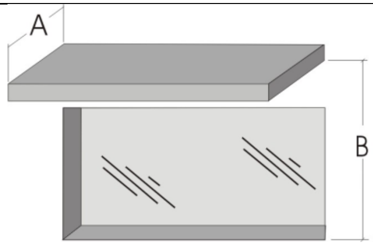


Heat Transfer in a Building: Solar Radiation

- The equation of the window to wall equivalent ratio (WWR_{eq}) is presented as follows:
  - $$WWR_{eq} = \frac{\sum(A_{wi} \times SHGC_{wi} \times ASF_{wi})}{A_v} + \frac{2 \times (A_{si} \times SHGC_{si})}{A_h}$$
  - A_{wi} = Area of an individual window
  - $SHGC_{wi}$ = Solar Heat Gain Coefficient of the individual window
  - ASF_{wi} = Architectural Shading factor of the window
  - A_{si} = Area of the skylight
  - $SHGC_{si}$ = Solar heat gain coefficient of the skylight
  - A_v = area of all vertical surfaces
  - A_h = area of all horizontal surfaces

Heat Transfer in a Building: Solar Radiation

The projection factor for overhangs is expressed as a dimensionless ratio defined as follows:

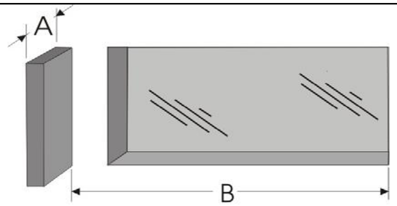


$$PF_{Overhang} = A/B$$

$PF_{Overhang}$ = Projection factor for overhangs (dimensionless)
A = Horizontal extension of the overhang from the vertical wall plane that contains the fenestration(m)

B = Distance between the bottom edge of the fenestration and the bottom edge of the overhang (m)

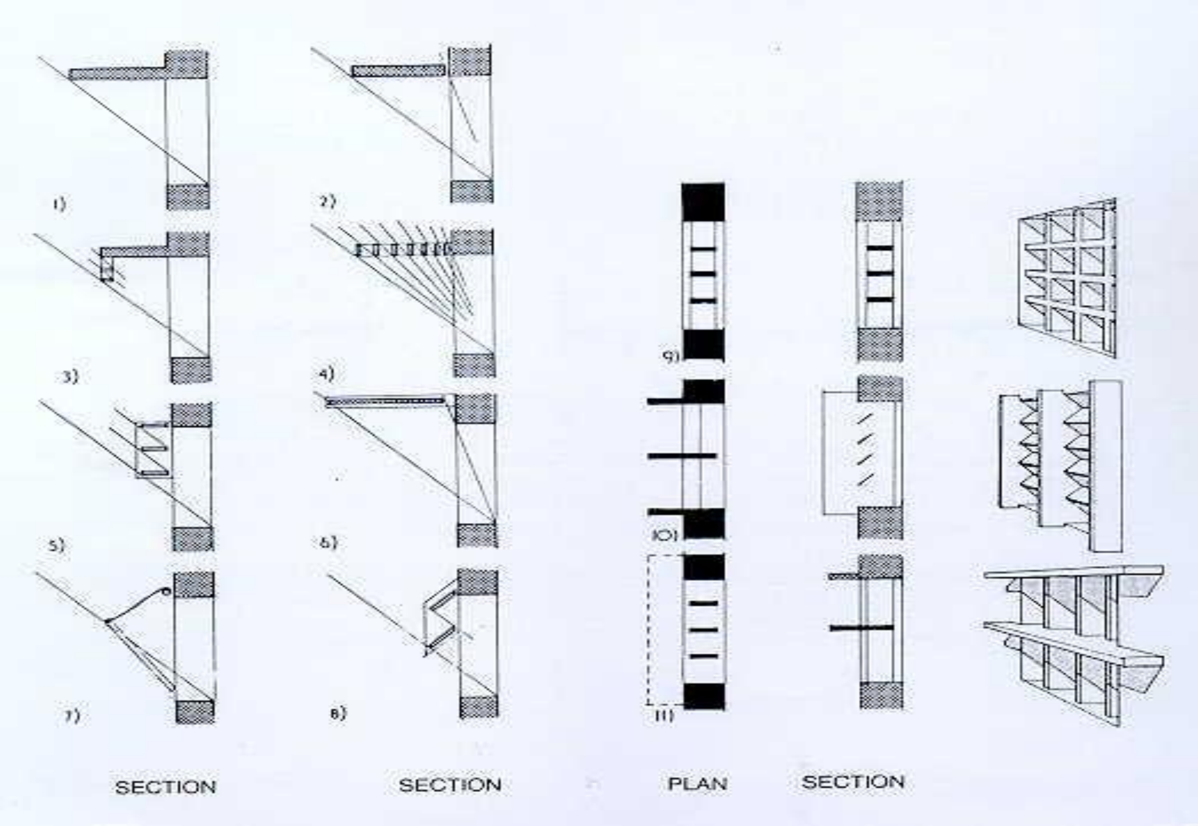
The projection factor for overhangs is expressed as a dimensionless ratio defined as follows:



$$PF_{Fins} = A/B$$

PF_{Fins} = Projection factor for overhangs (dimensionless)
A = horizontal extension of the fin from the vertical wall plane that contains the fenestration (m)

B = Distance between the farthest side of the fenestration to the face of fin closest to the fenestration(m)


1)
2)
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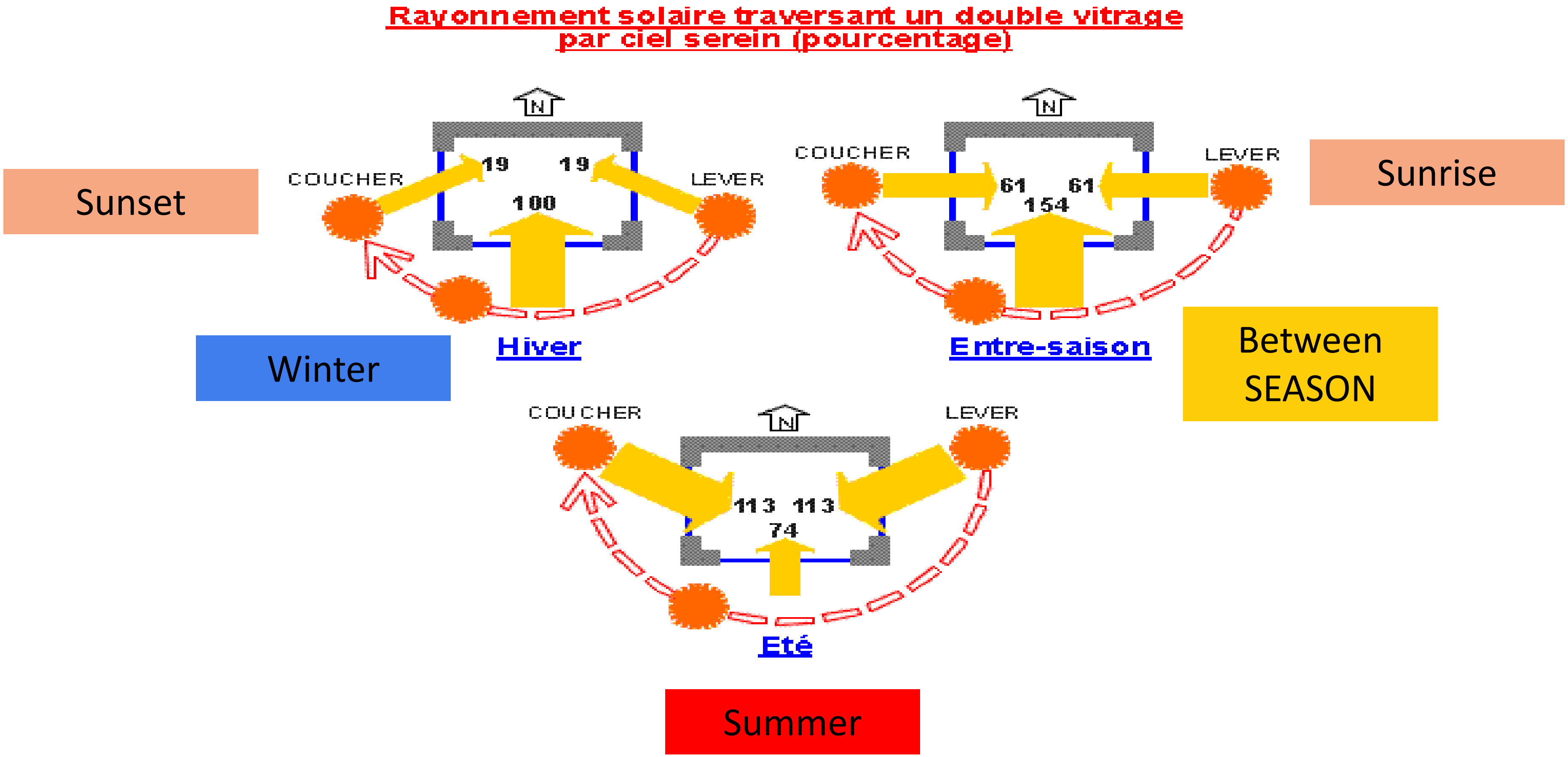
Solar radiation passing through double glazing under clear skies (percentage)



Heat Transfer in a Building: Solar Radiation

PF – Overhangs	ASF per orientation			
	N NE,NW	E EN,ES	W WN,WS	S SE,SW
PF ≤ 0.05	0.70	1	1	1
0.05 < PF ≤ 0.15	0.70	1	1	0.9
0.15 < PF ≤ 0.25	0.70	1	1	0.80
0.25 < PF ≤ 0.40	0.70	1	1	0.75
PF ≥0.40	0.70	1	1	0.70

PF – Fins	ASF per orientation			
	N	E EN,ES	W WN,WS	S SE,SW
PF ≤ 0.05	0.70	1	1	1
0.05 < PF ≤ 0.15	0.70	0.95	0.95	1
0.15 < PF ≤ 0.25	0.70	0.90	0.90	1
0.25 < PF ≤ 0.40	0.70	0.85	0.85	1
PF ≥0.40	0.70	0.80	0.80	1

Heat Transfer in a Building: Solar Radiation

- Example:
- Consider the same building that we have studied. All windows installed have a solar heat gain coefficient equal to 0.81. No shading devices are on any of the windows.

a) Calculate the window to wall equivalent ratio of the building.

b) Calculate the window to wall equivalent ratio of the building if the solar heat gain coefficient od the windows is 0.4.

- Solution:
- a)
- Area of windows on
  - Eastern Façade = 72 m^2
  - Northern Façade = 32 m^2
- All windows are composed of the same material, and their solar heat gain coefficient is 0.81.
- No shading devices are installed, hence the architectural shading factor is 1

Component	Area (m^2)
Windows East	72
Windows North	32

Heat Transfer in a Building: Solar Radiation

$$WWR_{eq} = \frac{\sum(A_{wi} \times SHGC_{wi} \times ASF_{wi})}{A_v} + \frac{2 \times (A_{si} \times SHGC_{si})}{A_h}$$

$$WWR_{eq} = \frac{32 \times 0.81 \times 1 + 72 \times 0.81 \times 1}{2 \times (15 \times 16 + 20 \times 16)} = \frac{84.24}{1120} = 0.075$$

7.5% of the solar radiation striking fenestration areas enters the building

b) If the windows installed have a solar heat gain coefficient equal to 0.4, the window to wall equivalent ratio becomes 0.037 which is almost half the original value.

Installing windows with low solar heat gain coefficient can result is significant energy and financial savings when the window to wall ratio is relatively high.

Heat Transfer in a Building: How to minimize solar radiation ?

- Install exterior sun control louvers
- Install external venetian blinds
- Adhere tinted and reflective polyester films to existing windows.
- Replace single pane windows with double pane windows.
- Plant deciduous trees if possible.

Measuring methodology

- The thermal transmittance requirement addresses the following building envelope components: Roofs, Walls, Windows and Skylights, Floors (exposed and semi exposed), and Slabs on ground.

- The maximum exposure to solar gain is demonstrated using the equivalent window to wall ratio WWR-eq that takes into consideration several factors that affect solar gain. These factors include window size, skylight, orientation, solar heat gain coefficient and architectural shading factor.

- Thermal standards for buildings - (TSBL) 2010 in Lebanon and the existing standards in the different targeted South-Mediterranean countries - are used as a baseline reference for this credit.

- As mentioned above, U env, U FACADE and WWR eq must be less than the reference values. Each of these values is evaluated apart by calculating its own reduction factor RF.

GUIDELINES

GRASS Guidelines


GUIDELINES

Residential Building

Version 1.0

March 2017

Certification Process

Application

↓

Pre-Assessment

↓

Actual Assessment & Verification


GUIDELINES

Non-Residential Building

Version 1.0

March 2017

GUIDELINES

Envelope

- Thermal Performance of Building Envelope
- Eco-Construction
- Eco-Roofs

GRASS Guidelines

Part 1 – Envelope

E 1 Thermal Performance of Building Envelope (TSBC)

E 1-1 Thermal Transmittance U_{ENV}

E 1-2 Thermal Transmittance U_{FACADE}

E 1-3 Window to Wall Ratio WWR_{EQ}

E 1-4 Slab on the ground Thermal Resistance

E 2 Eco-Construction

E 2-1 Material Category

E 2-2 Eco-Friendly Insulation Percentage

E 2-3 Mandatory Insulation

E2-3-1 Hot Water Pipes

E2-3-2 Refrigerants' Pipes

E2-3-3 Ducts

GUIDELINES

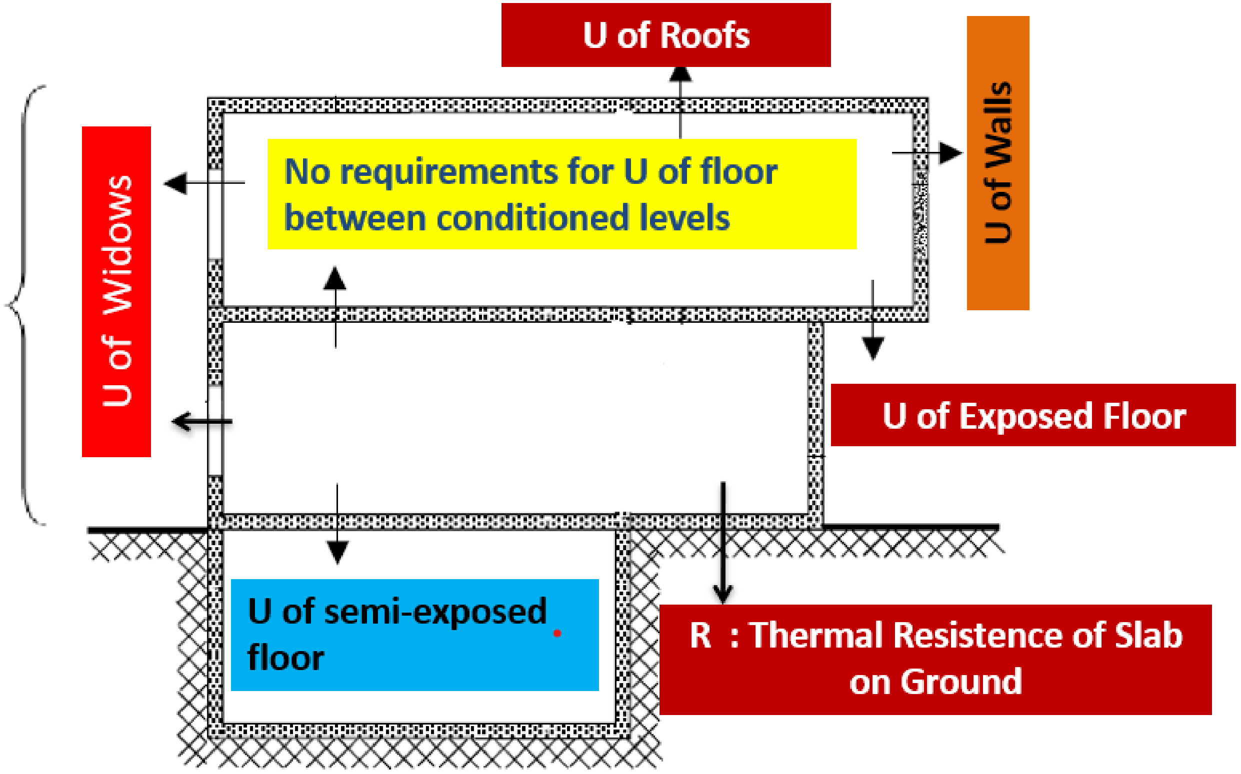
Envelope

- Thermal Performance of Building Envelope
- Eco-Construction
- Eco-Roofs

GRASS Guidelines

E 3 Eco Roofs (Green Roofs/Cool Roofs)
- E 3-1 Vegetated Roofs (Above 50%)
- E 3-2 Non-Vegetated Roofs (Less than 50%)
  - E 3-2-1 Initial of Solar Reflectance (ISR)
  - E 3-2-2 Maintenance of Solar Reflectance (MSR)
  - E 3-2-3 Thermal Emittance (TE)
  - E 3-2-4 SRI Alternative (Case TE not achieved)
    - E 3-2-4-1 Initial SRI
    - E 3-2-4-2 Maintenance of SRI
- E 3-3 Primary Scoring Points (PSP)
  - E 3-3-1 Vegetated Roofs
  - E 3-3-2 Non-Vegetated Roofs

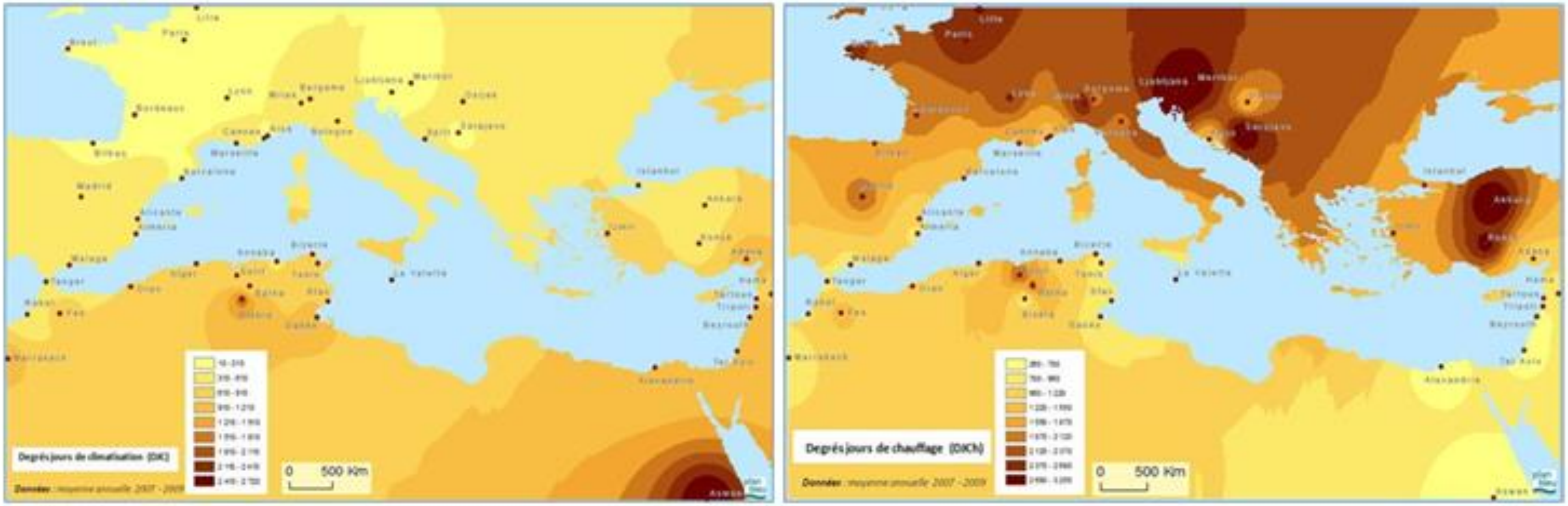
Requirements of Thermal Standard Maximum Thermal transmittance (U- value) by component



Climate Zones in Southern and Eastern Mediterranean Countries (SEMCs)

The 2 maps of Figure 21 allow a visualization of the needs for heating and cooling in the Mediterranean region. The baseline temperature selected is 18°C for heating degree-days and 21°C for cooling degree-days. From a visual standpoint, the darker the colour, the more significant the needs are. Also, and as may be observed, the needs of the SEMCs are mainly related to cooling, while those of the NMCs are more related to heating.

Figure 21 - Representation of the number of degree-days cooling (DDc) and the number of degree-days heating (DDh)



Source: Plan Bleu, June 2010 (based on 3-year mean data of www.degreedays.net)

Source : https://planbleu.org/wp-content/uploads/2011/06/2-EN_Batiment_Energie_CC.pdf

Climate Zones in Southern and Eastern Mediterranean Countries (SEMCs)

The SEMCs have climates that range from the Mediterranean type to the continental type. Characterised by a wet season that is fairly moderate and a markedly dry summer, the climate—as well as seismicity—have generated a common traditional architectural response as the outcome of right compromises.

The existing thermal regulations in the building sector in the SEMCs have delimited climatic zones in each country. An analysis and synthesis work is necessary to identify homogeneous climatic zones at SEMCs scale. In the meanwhile, it is proposed to consider 4 representative climates:

- **Z1 - Coastal zone** (example: Beirut, Lebanon). The climate is of a wet moderate Mediterranean type, characterized by rainfall concentrated in the winter and early spring, and hot and dry summers, with a fairly high relative humidity.
- **Z2 – Mountain zone** (example: Marrakech in Morocco, or High-Plateaux in Algeria). The climate tends to be arid, characterized by high seasonal and daytime temperature ranges. This zone presents a significant rainfall deficit in the summer. In the winter, night-time temperatures are cool. On the other hand, in the summer, the temperatures are scorching hot.
- **Z4** - **Desert zone** (example: Gafsa in Tunisia). In this zone, the climate is very dry and hot. There are, on the other hand, quite significant differences in temperature between day and night.
- **Z3** - **Continental zone** (example: Ankara in Turkey). The summers are sunny in the day and cool in the night. The winters are cold, with rain and snow.

As a complement to this climatic distribution, a zoning based on degree-days is of great use, for it highlights the needs for heating and cooling. Indeed, the degree-day is, for a given place, a value representative of the variance between the temperature of a given day and a temperature pre-defined threshold. It helps evaluate the energy expenditure for heating or cooling.

Source : https://planbleu.org/wp-content/uploads/2011/06/2-EN_Batiment_Energie_CC.pdf

Reference Thermal Transmittance Values per Component U-ref (W/m2.K) vs. climatic zone

Continental

Climatic Zone	Building category	U-value Roof	U-value Wall	U-value Window & Skylight	U-value Ground Floor Exposed*	U-value Ground Floor Semi-exposed**
1 Coastal Z1	1 Residential	0.71	1.60	5.80	1.70	2.00
	2 N Residential	0.71	1.26	5.80	1.70	2.00
2 Mid Z2 Mountain	1 Residential	0.63	0,77	4.00	0.77	1.20
	2 N Residential	0.55	0,65	3.30	0.70	1.20
3 Inland Plateau Z3	1 Residential	0.63	0,77	4.00	0.77	1.20
	2 N Residential	0.55	0,65	3.30	0.70	1.20
4 High Z4 Mountain	Residential	0.55	0.57	3.30	0.66	1.00
	2 N Residential	0.55	0.57	2.60	0.66	1.00

These U-ref are similar to Thermal regulation requirements Vs. Climate zones in Jordan, Morocco, Tunisia and Lebanon

At this stage no U-ref values for Desert zone (under development)

Reference Thermal Transmittance Values per Component U-ref (W/m2.K) - Jordan

4) Thermal Insulation of the Building Envelope: [1]

a. (MR): As the Following:

No.	requirement	points
1	Right place of insulation based on climate zone	None
2	U-value of Opaque walls- 0.57 $w/m^2.k$	None
3	U-value of Exposed Roofs- 0.55 $w/m^2.k$	None
4	U-value of Exposed Floors- 0.80 $w/m^2.k$	None
5	U-value of Separating walls- 2.00 $w/m^2.k$	None
6	U-value of Separating roof, floor- 1.20 $w/m^2.k$	None
7	Total U-value of walls- 1.60 $w/m^2.k$	None
8	Total U-value of Exposed roof, floor <1.60 $w/m^2.k$	None

5) Fenestration in the Building Envelope: [1]

a. (MR): As the Following:

No.	requirement	points
1	Glass 10%-40% area, less than 3.30 $w/m^2.k$	None
2	Glass 40%-99% area, less than 2.00 $w/m^2.k$	None
3	Total U-value of Wall, less than 1.6 $w/m^2.k$	None
4	Solar Heat Gain Coefficient, less than 0.25	None
5	Solar Heat Gain Coefficient for skylights <2% area, < 0.40. Skylights (2.1-5%), < 0.25	None
6	No skylights more than 5% area allowed	None
7	Visual transmittance of Glass, more than 0.45	None
8	Residential buildings= More than 10% window area for service zones, more than 15% window area for operational zones	None

Source : Green Building Guideline of Jordan - *Jordan International Energy Conference 2011 – Amman*

Reference Thermal Transmittance Values per Component U-ref (W/m2.K) - Palestine

4.4.2.4 مرجعية حساب النقاط

- *International Energy Conservation Code Sections 502.4, 503.2, 504, 505..*

الحدود العليا المسموح بها لكافة العاصر الانشائية في غلاف المبنى :

جدول (3-4) القيمة العظمى للانتقالية الحرارية U لعناصر الغلاف الخارجي المكشوفة

الرقم	العناصر الإنشائية بالغلاف الخارجي للمبنى	أعلى قيمة للانتقالية الحرارية U (W/m2.°K)
1	الجدار الخارجي	0.5
2	السقف الافقي المكشوف	0.39
3	السقف المائل المكشوف	0.39
4	الأرضيات الصلبة المتصلة بالأرض	0.46
5	الأرضيات المكشوفة	0.46
6	النوافذ الخارجية	2.46
7	الأبواب الخارجية المكشوفة	6

Reference Thermal Transmittance Values per Component U-ref (W/m2.K) - Palestine

جدول (4-5): القيمة العظمى للانتقالية الحرارية U لعناصر الغلاف الخارجي المكشوفة للمناطق الباردة

أعلى قيمة للانتقالية الحرارية U (W/m2.°K)	العناصر الإنشائية بالغلاف الخارجي للمبنى	
8 cm Insulation ? 0.35	الجدار الخارجي	1
12 cm Insulation ? 0.25	السقف الأفقي المكشوف	2
0.25	السقف المائل المكشوف	3
0.35	الأرضيات الصلبة المتصلة بالأرض	4
0.35	الأرضيات المكشوفة	5
2.0	النوافذ الخارجية	6
6	الأبواب الخارجية المكشوفة	7

و للعناصر شبه المكشوفة *(Semi-Exposed Elements)* في المناطق الباردة فإنه من المفضل التقيد بقيم الانتقالية الحرارية المبينة بالجدول *(4-6)*.

Reference Thermal Transmittance Values per Component U-ref (W/m2.K) - Palestine

العناصر الزجاجية الشفافة

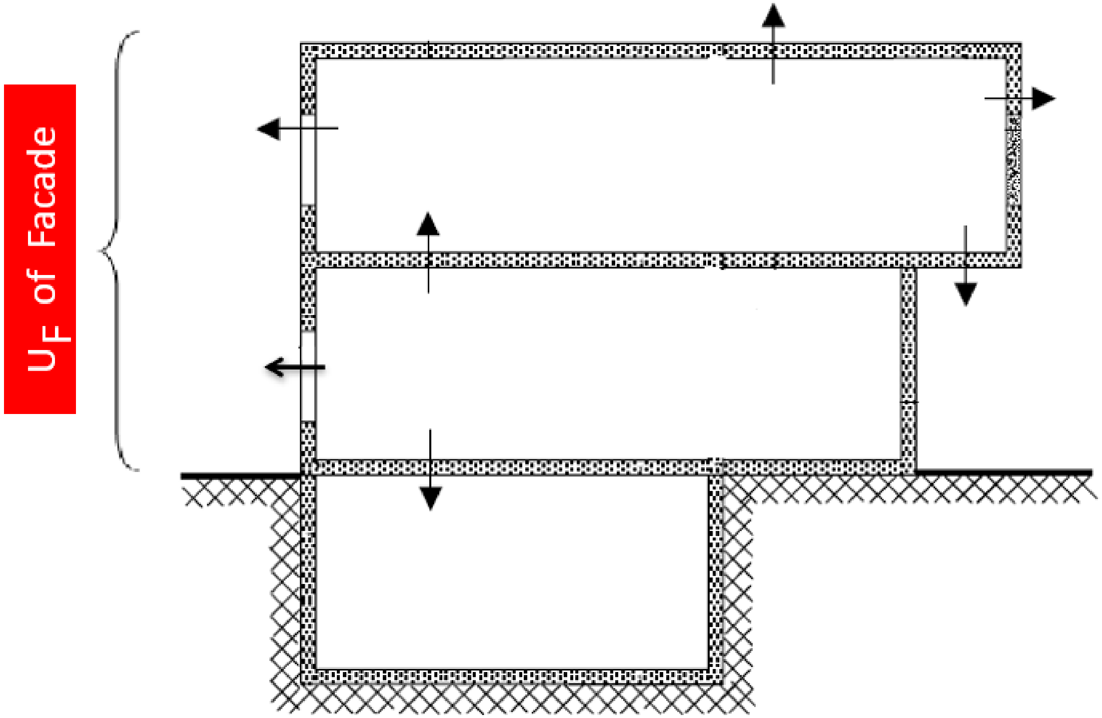
لكافة العناصر الزجاجية نفاذة الضوء في الجدران يجب أن تكون قيم معامل الانتقال الحراري ومعامل الظل و نفاذية الضوء أقل من الحدود المبينة في الجدول (7-4).

جدول (7-4) الحد الأعلى لقيم معامل الانتقال الحراري ومعامل الظل و نفاذية الضوء

	معامل انتقال الحرارة U- Value (لفصل الصيف)	معامل الظل	معامل نفاذية الضوء
للجدران			
نسبة الزجاج أقل من 40% من مساحة الجدار	2.1 w/m².K	0.4 max	25% min
نسبة الزجاج أكبر من 40% إلى 60% من مساحة الجدار	1.9 w/m².K	0.32 max	10% min
نسبة الزجاج أكبر من 60% من مساحة الجدار	1.9 w/m².K	0.25 max	10% min
للنوافذ والكوات في الأسقف			
نسبة الزجاج أقل من 10% من مساحة السقف	1.9 w/m².K	0.32 max	40% min
نسبة الزجاج أكبر من 10% من مساحة السقف	1.9 w/m².K	0.25 max	30% min
لواجهات المعارض	1.9 w/m².K	0.75 max	30% min

Not manufactured in the entire region

Requirements of Thermal Standard
Reference U- value of facade



Reference U-value of façade of buildings vs. climatic zone UFref

Climatic Zone	Building Category	U_{Fref} (W/m^2.K)
1 Coastal Zone	1 Res.	2.5
	2 N Res.	2.2
2 Western mid mountain	1 Res.	1.5
	2 N Res.	1.3
3 Inland Plateau	1 Res.	1.5
	2 N Res.	1.3
4 High Mountain	1 Res.	1.2
	2 N Res.	1.0

GUIDELINES

GRASS Guidelines

Criteria	$U_{ENV} \leq U_{ENV\text{-}REF}$	Reduction Factor RF	Scoring Points	
Thermal Transmittance of the Envelope	The Thermal Transmittance Value of the Envelope should be smaller or equal to the Reference Thermal Transmittance Value. The Reduction Factor is evaluated using the formula: $RF_{ENV} = \frac{U_{ENV-REF} - U_{ENV}}{U_{ENV-REF}} \times 100$	From 0 to 7%	7	150
		7.1% to 15%	18	
		15.1% to 30%	30	
		30.1% to 50%	40	
		≥ 50.1%	50	
Criteria	$U_{FAC} \leq U_{FAC\text{-}REF}$	Reduction Factor RF	Scoring Points	
Thermal Transmittance of the Facade	The Thermal Transmittance Value of the Facade should be smaller or equal to the Reference Thermal Transmittance Value. The reduction Factor is evaluated using the formula: $RF_{FAC} = \frac{U_{FAC-REF} - U_{FAC}}{U_{FAC-REF}} \times 100$	From 0 to 7%	7	
		7.1% to 15%	18	
		15.1% to 30%	30	
		30.1% to 50%	40	
		≥ 50.1%	50	
Criteria	$WWR_{EQ} \leq WWR_{EQ\text{-}REF}$	Reduction Factor RF	Scoring Points	
Window to Wall Ratio	The equivalent Window to Wall Ratio of the building should be smaller or equal to the Reference Window to Wall Ratio. The reduction Factor is evaluated using the formula: $RF_{WWR_{EQ}} = \frac{WWR_{EQ-REF} - WWR_{EQ}}{WWR_{EQ-REF}} \times 100$	From 0 to 7%	7	
		7.1% to 15%	18	
		15.1% to 30%	30	
		30.1% to 50%	40	
		≥ 50.1%	50	
Criteria	Slab on Ground Thermal Resistance ≥ Requirements in TSBL	Prerequisite		

Measuring methodology

$$RFx = (Yref - Y) * 100/Y ref$$

Where x = Envelope, Façade, or Window to Wall Ratio,
Y_{ref} = $U_{env\ ref}$, $U_{Fac\ ref}$, $WWR_{eq\ ref}$
Y= U_{env}, U_{Fac}, or WWR_{eq}

Measuring methodology

- Regarding Slabs' minimum thermal resistance, slabs on ground are to be insulated under the outside perimeter with a specified width of thermal insulation having the required thermal resistance (R value) as specified in the table below for the Lebanese case as an example (prerequisite). This requirement is limited to slabs on ground constituting the floors of conditioned spaces only.

Climate Zone	Building Category	Minimum Thermal Resistance, R (m2.K/W)	Insulation Width (m)
1	Residential and Commercial	NR	NR
2	Residential and Commercial	0.75	1.00
3	Residential and Commercial	1.00	1.25
4	Residential and Commercial	1.25	1.50

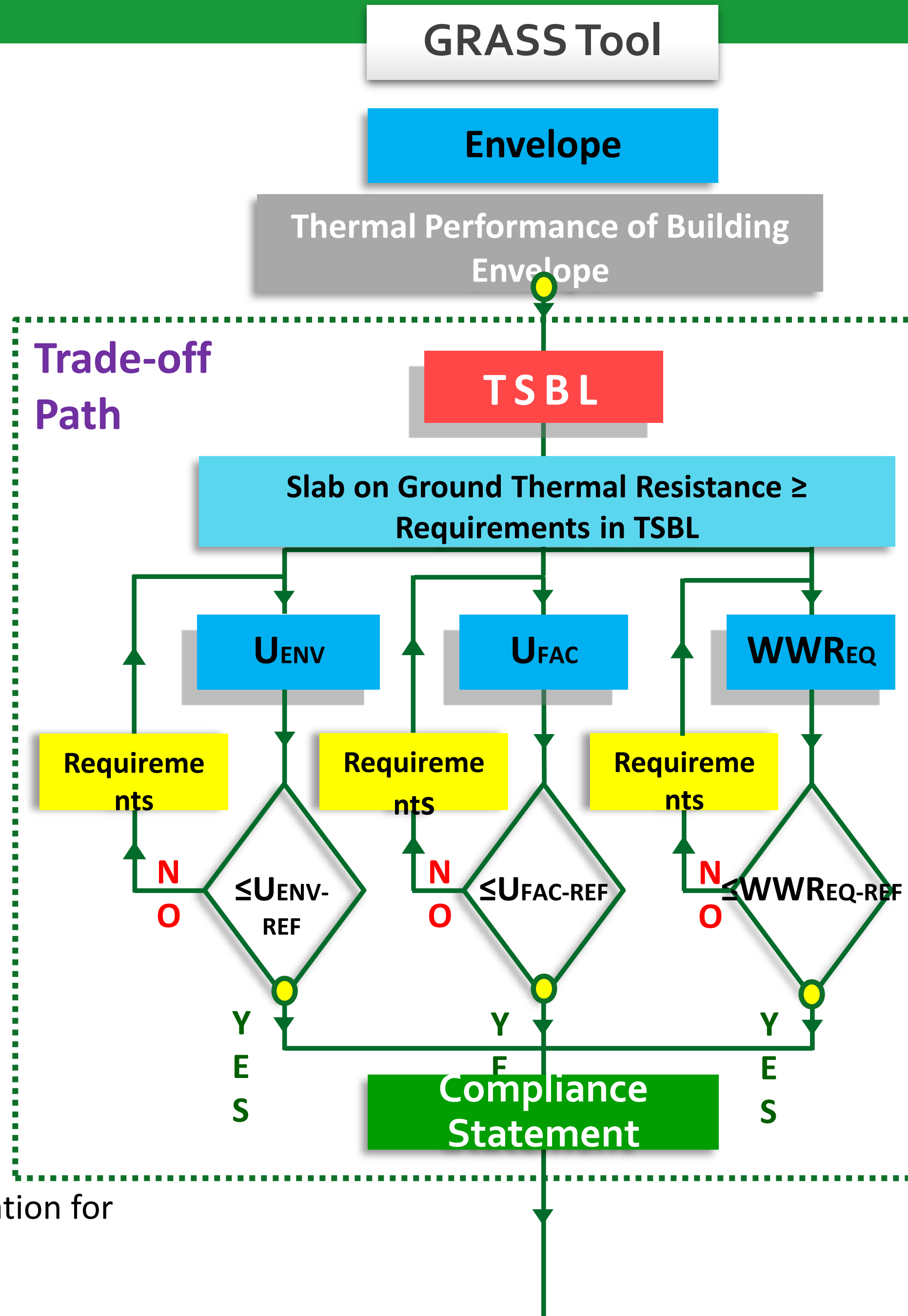
Measuring methodology

- U env, U Fac and WWR-eq are calculated and their values must be less than the maximum reference values given by the each national thermal standard (if existing – if not refer to the standard available on the platform).
- U env, U Fac and WWR-eq can be calculated using the tool available on the platform
- The assessor will enter the required values so that the software can compute these values. Then these values are compared against the TSBL reference values already incorporated within the library of the software.
- Regarding the thermal resistance for slabs, R-value must comply with the minimum values specified by the thermal standards. This value must be submitted to the assessor along with the insulation width installed.
- The four values must comply with the thermal standard or else the building will not be qualified for certification.

TOOLS

GRASS Tool

Envelope
- Thermal Performance of Building Envelope
- Eco-Construction
- Eco-Roofs



[TSBL 2010] for Lebanon – National Thermal regulation for others countries

TOOLS

GRASS Tool

Overall Envelope UVALUE

$$U_{ENV} = \sum \frac{(U_i \times A_i)}{A}$$

- **Ui: Thermal transmittance of the individual component.**
- **Ai: Area of individual component.**
- **A: Area of all envelope components .**

Thermal Performance of Building Envelope

Slab on Ground Thermal Resistance

U Envelope

U Facade

WWR Equivalent

Condition is achieved if

$$U_{ENV} \leq U_{REF}$$

TOOLS

GRASS Tool

Thermal Performance of Building Envelope

Slab on Ground Thermal Resistance

U Envelope

U Facade

WWR Equivalent

UFAC Calculation

$$U_{FAC} = \sum \frac{(U_i \times A_i)}{A}$$

- **Ui: thermal transmittance of the exposed walls and windows.**
- **Ai: Area of individual component.**
- **A: Area of all exposed walls including windows in all orientation.**

Condition is achieved if

$$U_{FAC} \leq U_{FAC-REF}$$

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Component	U-Value $\frac{W}{m^2K}$	Area (m^2)	U × A
Windows East	4	80	320
Windows North	4	40	160
Wall East	2.5	250	625
Wall West	2.2	330	726
Wall North	2.5	220	550
Wall South	2.2	250	550
Roof	2.2	300	660
Floor semi-exposed	1.5	300	450
Total		1770	4041
$U_{Env}\left(\frac{W}{m^2K}\right)$			
$U_{Fac}\left(\frac{W}{m^2K}\right)$			

Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope

Component	U-Value $\frac{W}{m^2K}$	Area (m^2)	$U \times A$
Windows East	4	80	320
Windows North	4	40	160
Wall East	2.5	250	625
Wall West	2.2	330	726
Wall North	2.5	220	550
Wall South	2.2	250	550
Roof	2.2	300	660
Floor semi-exposed	1.5	300	450
Total		1770	4041
$U_{Env} \left(\frac{W}{m^2K}\right)$			2.28
$U_{Fac} \left(\frac{W}{m^2K}\right)$			2.50

Uref Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope Climate Zone : Inland Plateau

Component	U-Value $\frac{W}{m^2K}$	Area (m^2)	$U \times A$
Windows East	3.3	80	264
Windows North	3.3	40	132
Wall East	0.65	250	162.5
Wall West	0.65	330	214.5
Wall North	0.65	220	143
Wall South	0.65	250	162.5
Roof	0.55	300	165
Floor semi-exposed	1.2	300	360
Total		1770	1603.5
$U_{Env-Ref}\left(\frac{W}{m^2K}\right)$			
$U_{Fac-Ref}\left(\frac{W}{m^2K}\right)$			

Uref Heat Transfer in a Building: Thermal Transmittance of a Building's Envelope Climate Zone : Inland Plateau

Component	U-Value $\frac{W}{m^2K}$	Area (m^2)	U × A
Windows East	3.3	80	264
Windows North	3.3	40	132
Wall East	0.65	250	162.5
Wall West	0.65	330	214.5
Wall North	0.65	220	143
Wall South	0.65	250	162.5
Roof	0.55	300	165
Floor semi-exposed	1.2	300	360
Total		1770	1603.5
$U_{Env-Ref}\left(\frac{W}{m^2K}\right)$			0.905
$U_{Fac-Ref}\left(\frac{W}{m^2K}\right)$			0.922

No Compliance – U-values should be Reduced

TOOLS

GRASS Tool

Thermal Performance of Building Envelope

Slab on Ground Thermal Resistance

U Envelope

U Facade

WWR Equivalent

WWR_{EQ} Calculation

$$WWR_{EQ} = \sum \frac{(Aw_i \times SHGCw_i \times ASFw_i)}{Av} + 2\sum \frac{(As_i \times SHGCs_i)}{Ah}$$

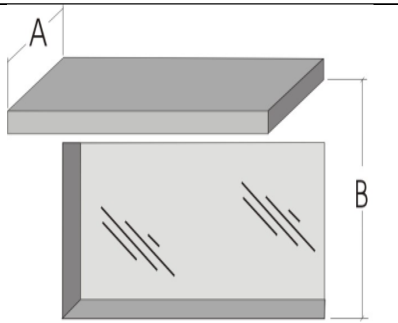
- **Awi: Area of the individual window**
- **SHGCwi: Solar Heat Gain Coefficient of the individual window.**
- **ASFwi: Architectural shading factor of the individual window.**
- **Av: Area of all vertical surfaces (opaque walls + windows).**
- **Asi: Area of the individual skylight.**
- **SHGCsi: Solar Heat Gain Coefficient of the individual skylight.**
- **Ah: Area of all horizontal surfaces (roofs + skylights).**

Condition is achieved if

$$WWR_{EQ} \leq WWR_{REF}$$

Projection Factor PF

The projection factor for overhangs is expressed as a dimensionless ratio defined as follows:

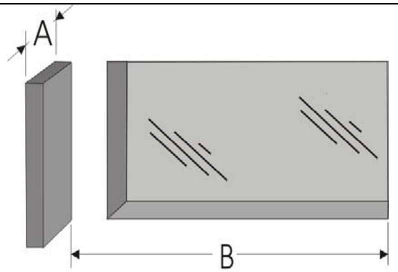


$$PF_{Overhang} = A/B$$

$PF_{Overhang}$ = Projection factor for overhangs (dimensionless)
A = Horizontal extension of the overhang from the vertical wall plane that contains the fenestration(m)

B = Distance between the bottom edge of the fenestration and the bottom edge of the overhang (m)

The projection factor for overhangs is expressed as a dimensionless ratio defined as follows:



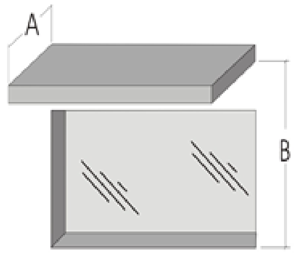
$$PF_{Fins} = A/B$$

PF_{Fins} = Projection factor for overhangs (dimensionless)
A = horizontal extension of the fin from the vertical wall plane that contains the fenestration (m)

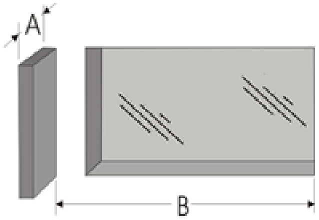
B = Distance between the farthest side of the fenestration to the face of fin closest to the fenestration(m)

Architectural Shading Factor ASF

PF – Overhangs	ASF per orientation			
	N NE,NW	E EN,ES	W WN,WS	S SE,SW
PF ≤ 0.05	0.70	1	1	1
0.05 < PF ≤ 0.15	0.70	1	1	0.9
0.15 < PF ≤ 0.25	0.70	1	1	0.80
0.25 < PF ≤ 0.40	0.70	1	1	0.75
PF ≥0.40	0.70	1	1	0.70



PF – Fins	ASF per orientation			
	N	E EN,ES	W WN,WS	S SE,SW
PF ≤ 0.05	0.70	1	1	1
0.05 < PF ≤ 0.15	0.70	0.95	0.95	1
0.15 < PF ≤ 0.25	0.70	0.90	0.90	1
0.25 < PF ≤ 0.40	0.70	0.85	0.85	1
PF ≥0.40	0.70	0.80	0.80	1



Windows to wall ratio equivalent WWR-eq

	Area m^2	PF-overhangs	ASF	SHGC
Windows East	40	0.35		0.75
Windows South	80	0.35		0.75
Windows West	40	0.35		0.75
Windows North	80	0.35		0.75

- Total Windows Area 240 m^2
- Total Façade Area (walls + windows) 1200 m^2
- Windows to wall ratio = Windows area/Total Façade area =
-

$$WWR_{EQ} = \\ = \sum \frac{(Aw_i \times SHGCw_i \times ASFw_i)}{Av} + 2 \sum \frac{(As_i \times SHGCs_i)}{Ah}$$

=

Windows to wall ratio equivalent WWR-eq

	Area m^2	PF-overhangs	ASF	SHGC
Windows East	40	0.35	1	0.75
Windows South	80	0.35	0.75	0.75
Windows West	40	0.35	1	0.75
Windows North	80	0.35	0.7	0.75

- Total Windows Area 240 m^2
- Total Façade Area (walls + windows) 1200 m^2
- Windows to wall ratio = Windows area/Total Façade area = 0.2

$$WWR_{EQ} = \sum \frac{(Aw_i \times SHGCw_i \times ASFw_i)}{Av} + 2\sum \frac{(As_i \times SHGCs_i)}{Ah}$$

= 2x 40x1x0.75 + 80x0.75x.75+80x0.7x0.75

1200

= 0.117

GRASS Tools Development

TOOLS

GRASS Tool

Thermal Performance of Building Envelope

Slab on Ground Thermal Resistance

U Envelope

U Facade

WWR Equivalent

All conditions are met

$U_{ENV} \leq U_{REF}$

$U_{\mathbf{FAC}} \leq U_{\mathbf{FAC}-REF}$

$WWR_{EQ} \leq WWR_{REF}$

Compliance Statement

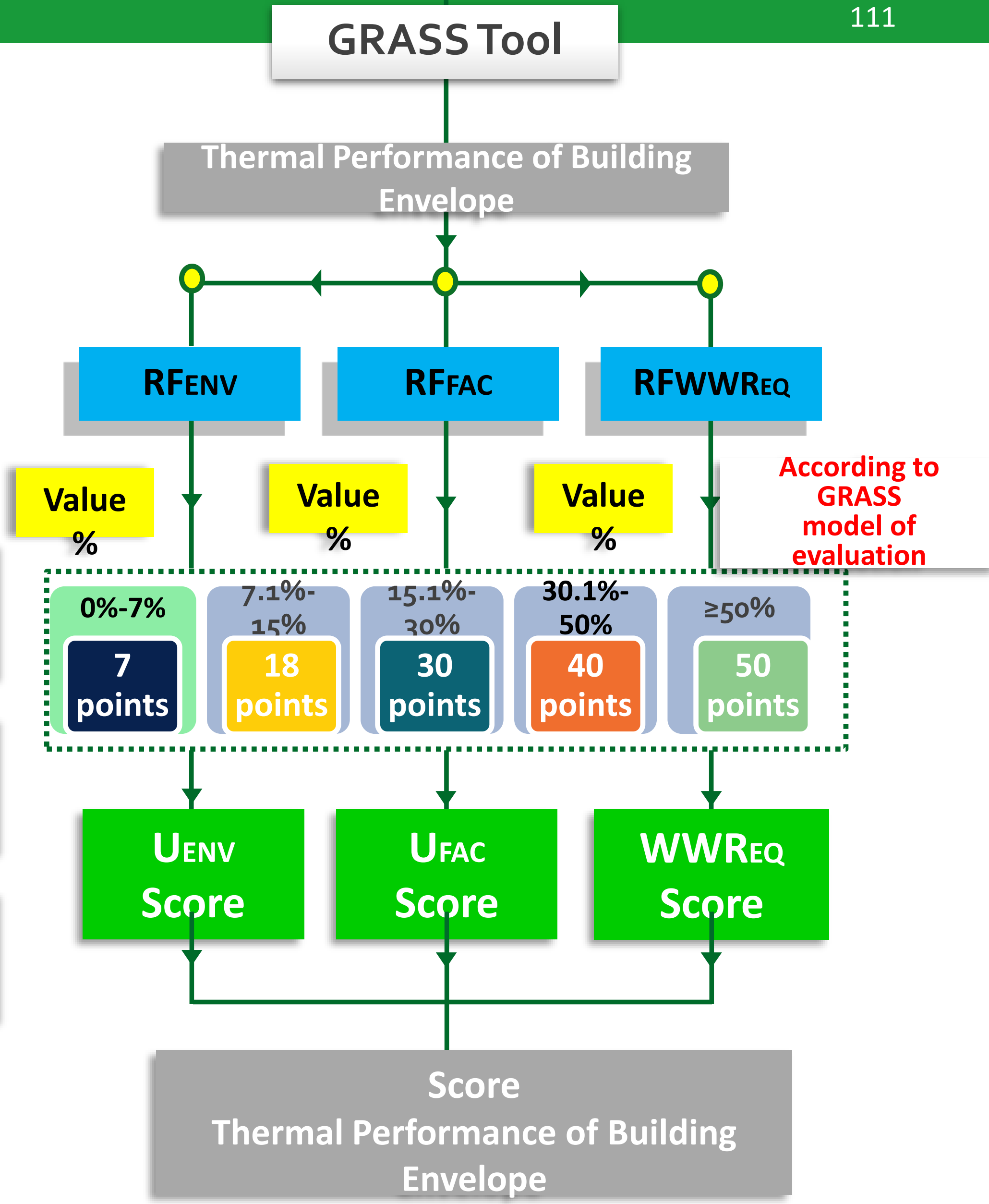
TOOLS

GRASS Tool

$$RF_{ENV} = \frac{U_{ENV-REF} - U_{ENV}}{U_{ENV-REF}} \times 100$$

$$RF_{FAC} = \frac{U_{FAC-REF} - U_{FAC}}{U_{FAC-REF}} \times 100$$

$$RF_{WWR_{EQ}} = \frac{WWR_{EQ-REF} - WWR_{EQ}}{WWR_{EQ-REF}} \times 100$$



How To Comply With GRASSMED?

The scoring points for Thermal Performance of Building Envelope and the requirements for both commercial and residential buildings are given in the table below:

Compliance with Requirements	Scoring Points
Maximum Scoring for Residential and Commercial Buildings	150
Minimum Slab on the ground Thermal Resistance thickness	Prerequisite
RF U_{env}	
0% - 7%	7
7.1%-15%	18
15.1%-30%	30
30.1%-50%	40
≥ 50.1%	50
RF U_{fac}	
0% - 7%	7
7.1%-15%	18
15.1%-30%	30
30.1%-50%	40
≥ 50.1%	50
RF WWR_{eq}	
0% - 7%	7
7.1%-15%	18
15.1%-30%	30
30.1%-50%	40
≥ 50.1%	50

Calculation of Scoring : Thermal Performance of Building Envelope

Uenv-Ref	Uenv	(Uenv-Ref – Uenv)x100 / Uenv-Ref	Scoring
0.9	0.6	(0.9-0.6)x100/0.9 = 33%	
Ufac-Ref	Ufac	(Ufac-Ref – Ufac)x100 / Uenv-Ref	Scoring
1.1	0.7	(1.1-0.7)x100/1.1=36.4%	
WWW-Ref	WWW-eq	(WWW-Ref – WWW-eq)x100 / WWW-Ref	Scoring
0.19	0.12	(019-0.12)x100/0.19=52.6%	
Scoring : Thermal Performance of Building Envelope			

Calculation of Scoring : Thermal Performance of Building Envelope

Uenv-Ref	Uenv	(Uenv-Ref – Uenv)x100 / Uenv-Ref	Scoring
0.9	0.6	(0.9-0.6)x100/0.9 = 33%	40
Ufac-Ref	Ufac	(Ufac-Ref – Ufac)x100 / Uenv-Ref	Scoring
1.1	0.7	(1.1-0.7)x100/1.1=36.4%	40
WWW-Ref	WWW-eq	(WWW-Ref – WWW-eq)x100 / WWW-Ref	Scoring
0.19	0.12	(019-0.12)x100/0.19=52.6%	50
Scoring : Thermal Performance of Building Envelope			130

Use of the TSBC Software
Small Hotel Amman

Component		Area (m^2)
Windows East & West		40.8 x 2
Windows North & South		61.2 x 2
Wall East		199.2
Wall West		199.2
Wall North		298.8
Wall South		298.8
Roof		600
Floor semi-exposed		600
$U_{Env-Ref}\left(\frac{W}{m^2K}\right)$		
$U_{Fac-Ref}\left(\frac{W}{m^2K}\right)$		

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