Basic Principles - Lecture II

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MS State University | CAAD

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Basic Principles

The original purpose of a building is to provide shelter and to maintain a comfortable or at least livable internal temperature. Other purposes include security, privacy and protection from wind and weather. To feel comfortable in a thermal sense, a human has to be able to release a well-defined amount of *heat.* If this gets difficult, a person will either feel cold or hot. The human body operates as a chemical reactor that converts chemical energy of food and respiratory oxygen into mechanical work and heat.

(Source: ASHRAE Fundamentals (1993))

ASHRAE - The American Society of Heating, Refrigerating and Air-Conditioning Engineers

The heating, cooling, and lighting of buildings are accomplished by adding or removing energy.

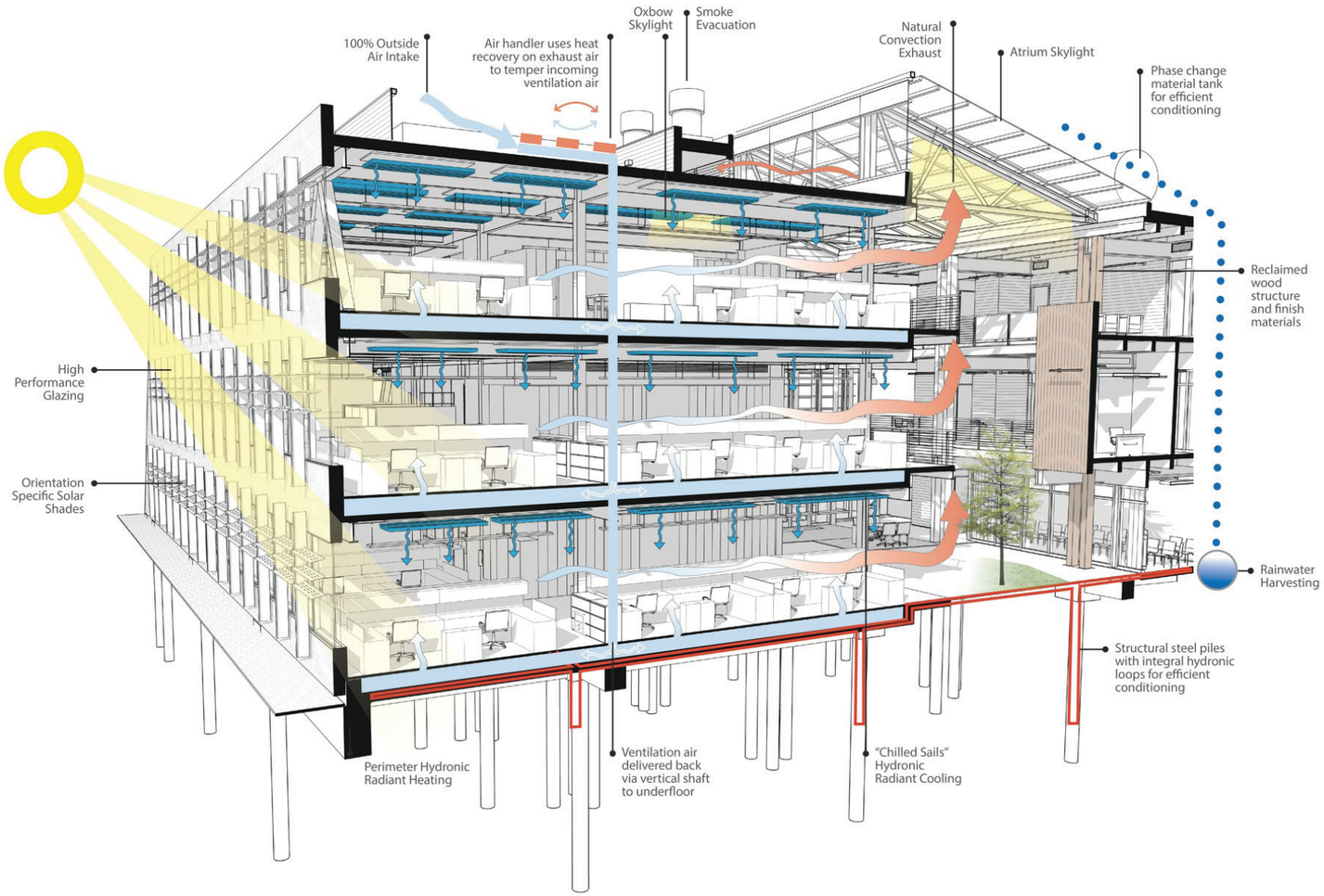
Energy in the form of heat

- *Sensible heat*: can be measured with a thermometer
- *Latent heat*: the change of state or phase change of a material
- *Radiant heat*: a form of electromagnetic radiation

Heat transfer

Heat moves through building assemblies primarily in three ways.

- *Conduction*
- *Convection*
- *Radiation*



Federal Center South Building 1202 / ZGF Architects
Energy strategies: High performance glazing, perimeter hydronic heating, hydronic radiant cooling, phase change material tank for efficient cooling, natural convection exhaust.

https://www.archdaily.com/447019/federal-center-south-building-1202-zgf-architects?ad_medium=gallery

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Basic Principles

Sensible heat

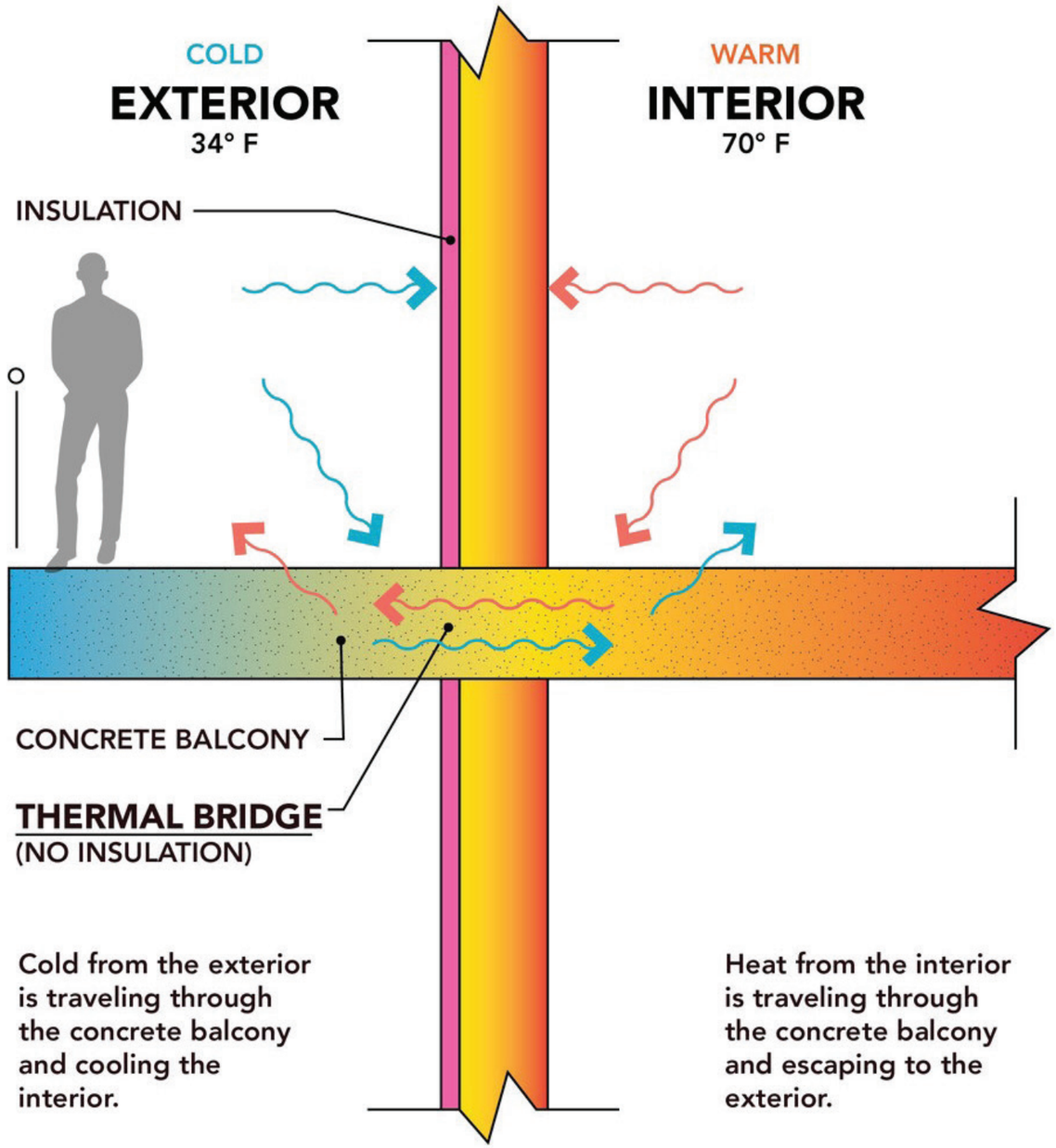
The random motion of molecules is a form of energy called sensible heat. An object whose molecules have a more intense random motion is said to be hotter and to contain more heat. Because this type of heat can be measured by a thermometer and felt by our skin, it is called sensible heat. If two objects are brought into contact, some of the more intense random motion of one object will be transferred to the object with less by the heat-flow mechanism called *conduction*.

The sensible heat content of an object is a function not only of its mass and temperature but also of it's heat capacity.

(Source: Heating, Cooling, Lighting by Lechner)

A **thermal bridge**, also called a cold bridge, heat bridge, or thermal bypass, is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer.

(Wikipedia)



(Image source: https://civilengineering4u.files.wordpress.com/)

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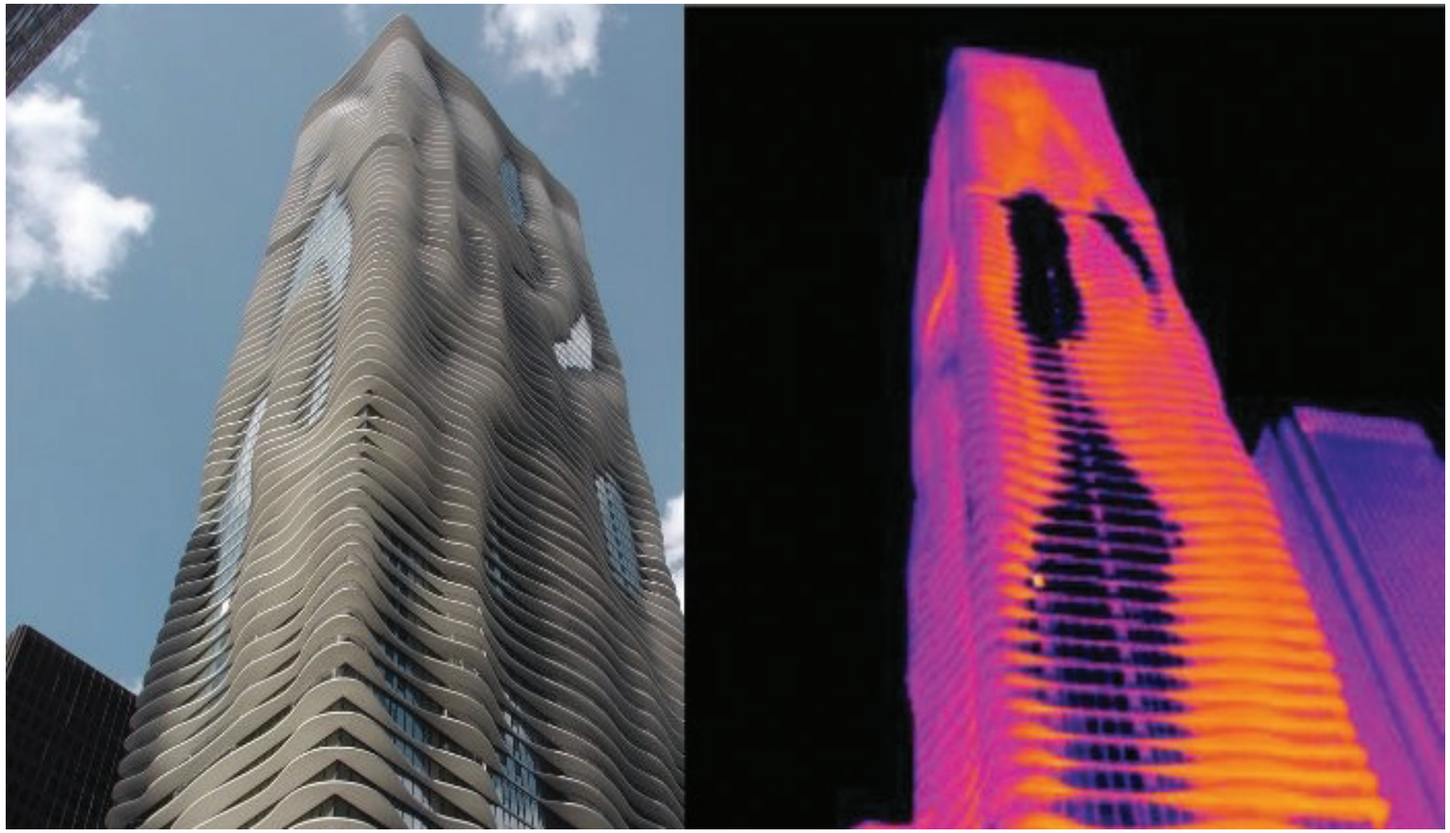
Basic Principles

Conduction

Movement of heat energy directly through solid materials from molecule to molecule.

Building materials conduct energy at different rates. Metals, such as copper and steel, for example, have high conductivity, meaning heat energy moves through them at a very efficient rate. Fiberglass batts and rigid foam, on the other hand, have low conductivity. Materials that are poor conductors serve as insulators when they are placed between more-conductive materials in an assembly such as a wall or a roof. The flow of heat through an assembly of materials is slowed down appreciably by insulating materials. Wood is somewhere in the middle for conductivity. It's not a good insulator unless it is shredded and has lots of air pockets between the wood fibers. (The secret behind most insulation is air pockets that disrupt the conductive heat flow through a material.)

(Source https://www.jlconline.com/)



Aqua Tower, Chicago with thermal image showing conduction/heat transfer through concrete slabs/balconies.
(Image source: https://medium.com/)

Images showing conduction / heat transfer through balcony with and without thermal break.
(Image source:https://www.constructionspecifier.com/)

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Basic Principles

Latent heat

The heat required to convert a solid into a liquid or vapor, or a liquid into a vapor, without change of temperature. Large amounts of energy are needed to break the bonds between molecules when a change of state occurs. ““Heat of fusion” is required to melt a solid and “heat of vaporization” is required to change a liquid into a gas.

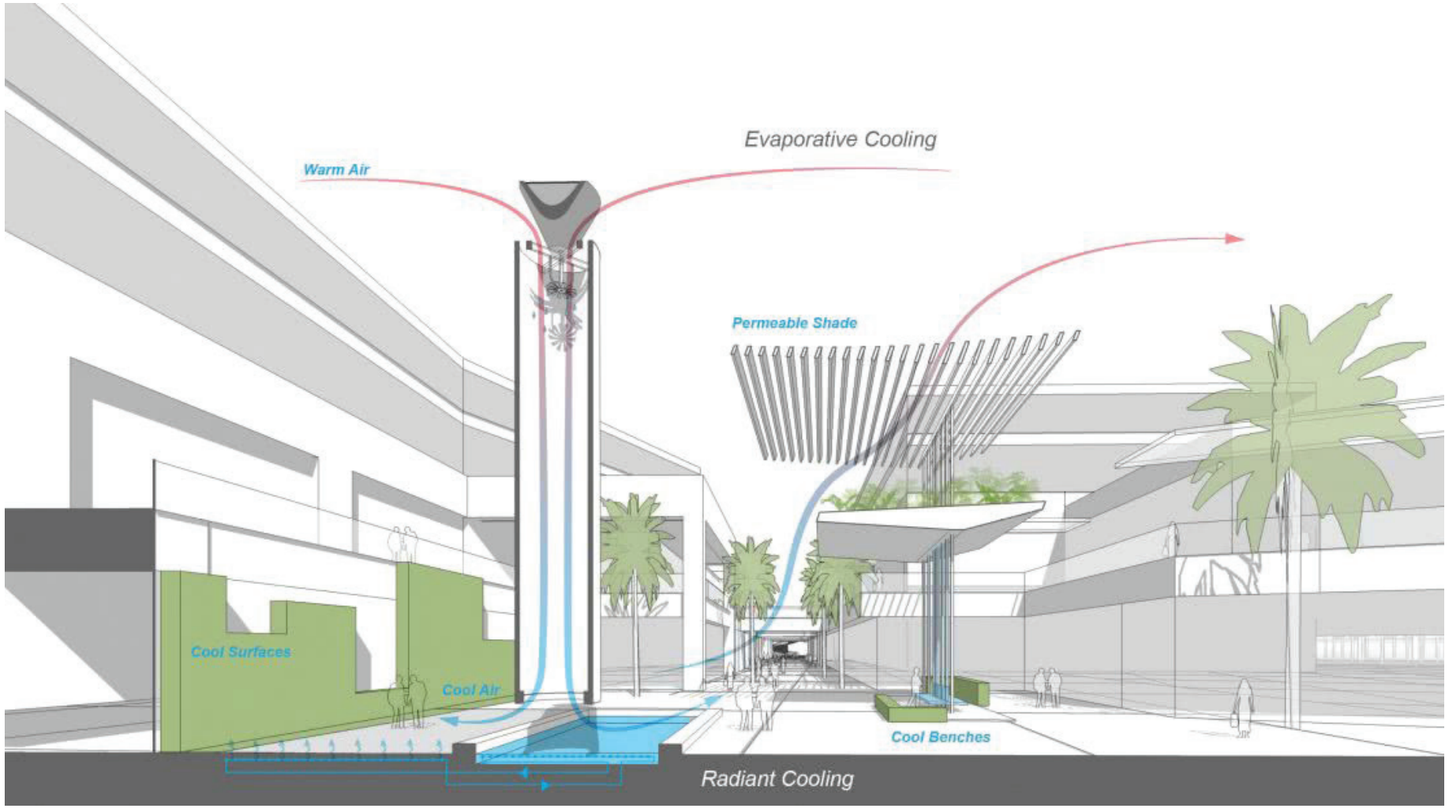
Latent heat is a compact and convenient form for storing and transferring heat. However, since the melting and boiling points of water are not always suitable for heating and cooling buildings, substances called phase change materials (PCM) are used. When used in air conditioners, these materials are called refrigerants.

Evaporative cooling

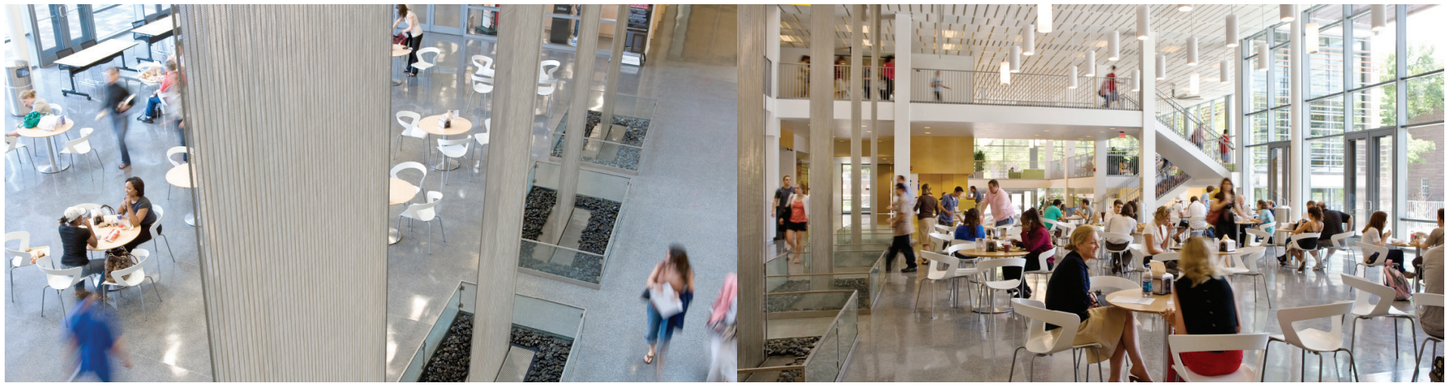
Works on the principle of water evaporation through which the air is cooled down to a comfortable temperature. It is a cooling and ventilation technique that uses water as its refrigerant. During the evaporative cooling process, water is evaporated in a stream of air and passes from a liquid to a gas. This transition requires energy, which is extracted from the air in the form of heat. As a result of this process, the air is cooled down.

(Source: Heating, Cooling, Lighting by Lechner)

Cooling Tower - Evaporating water at the top of a cooling tower creates a downdraft of cooler air that can then be circulated to a specific space or area. The amount of cool air from the tower is dependent on outdoor humidity, the height of the tower, and the amount of water being evaporated.



Master Plan for CSUSB (California State University, San Bernardino)



Water walls for evaborative / ambient cooling
Lavin Bernick Center, Tulane University
VJAA
VJAA - https://www.youtube.com/watch?v=rqJ9Hqnieh8

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Basic Principles

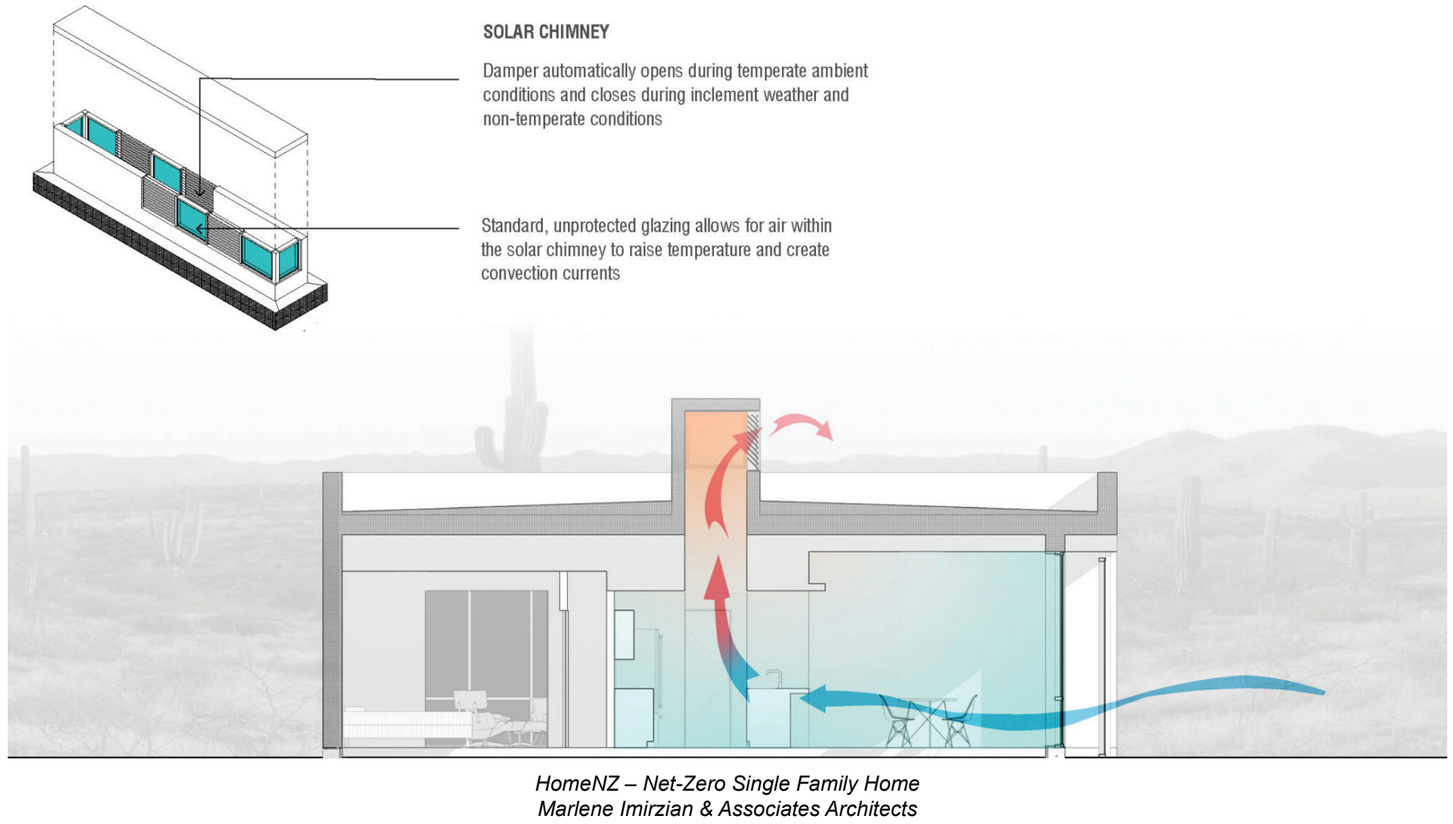
Convection

The flow of heat within a fluid, with warmer fluids rising and colder fluids falling. In buildings, this fluid is air.

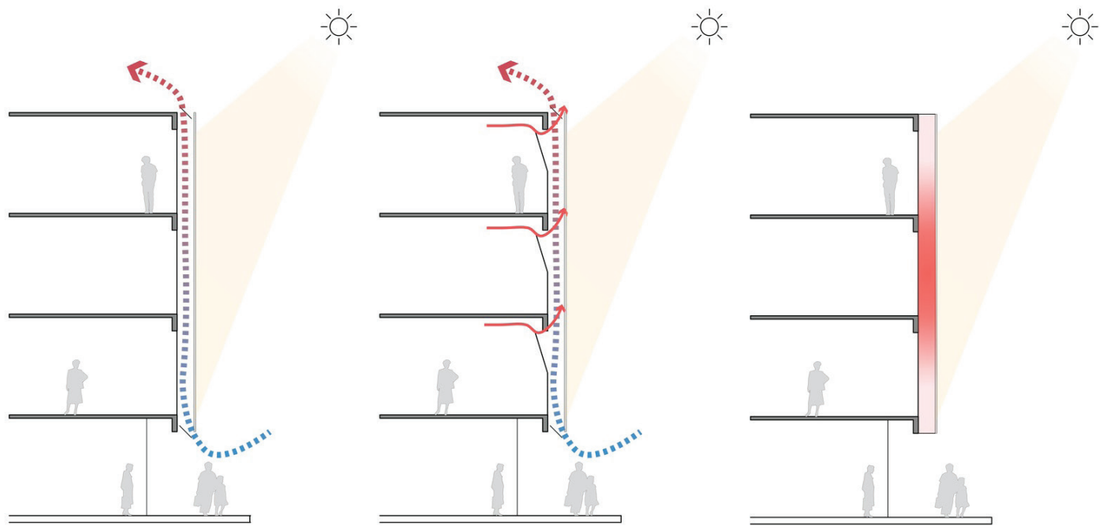
In air, convection is often called the “stack effect.” As air warms, the molecules move farther apart, and the air becomes more buoyant/less dense, floating upwards. As that air rises, cold air is pulled from below to replace it. The resulting currents transfer heat by the mechanism called **natural convection.** This heat-transfer mechanism is very much dependent on gravity and, therefore, heat never convects down. Since we are surrounded by air, natural convection in air is a very important heat-transfer mechanism in our goal of being thermally comfortable.

In a boiler or heat pump, warmed water circulates in a similar way, and piping systems can be designed to use this “thermosiphon” to circulate water.

(Sources: www.jlconline.com and Heating, Cooling, Lighting by Lechner)



HomeNZ – Net-Zero Single Family Home
Marlene Imirzian & Associates Architects



Stack effect being used in a double facade system to cool/ventilate when temps. are warm outside and mitigate heat loss when temps are cold outside.

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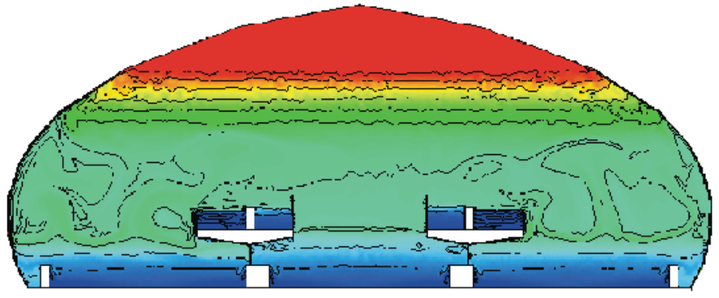
Convection

When there is no air motion due to the wind or a fan, natural convection currents tend to create layers that are at different temperatures. In rooms, hot air collects near the ceiling and cold air near the floor. This stratification (also, **heat stratification)** can be an asset in the summer and a liability in the winter.

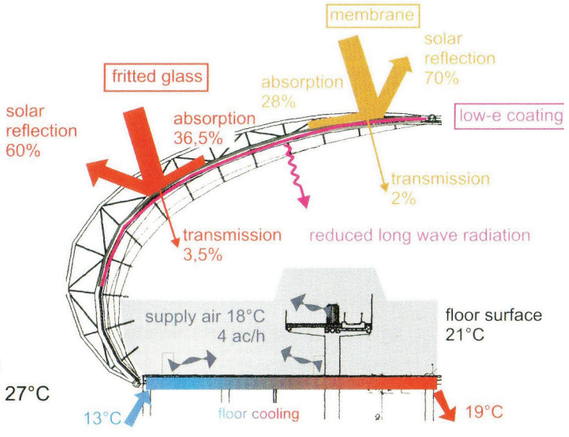
(Source: Heating, Cooling, Lighting by Lechner)

Images and diagrams of Passenger Terminal Complex,
Suvarnabhumi Airport - Bangkok, Thailand
Architect: Helmut Jahn



Heat stratification diagram showing comfortable conditions at passenger level.

T_{air}= 24°C
$T_{operative}$= 27°C



Heating, cooling and solar strategy

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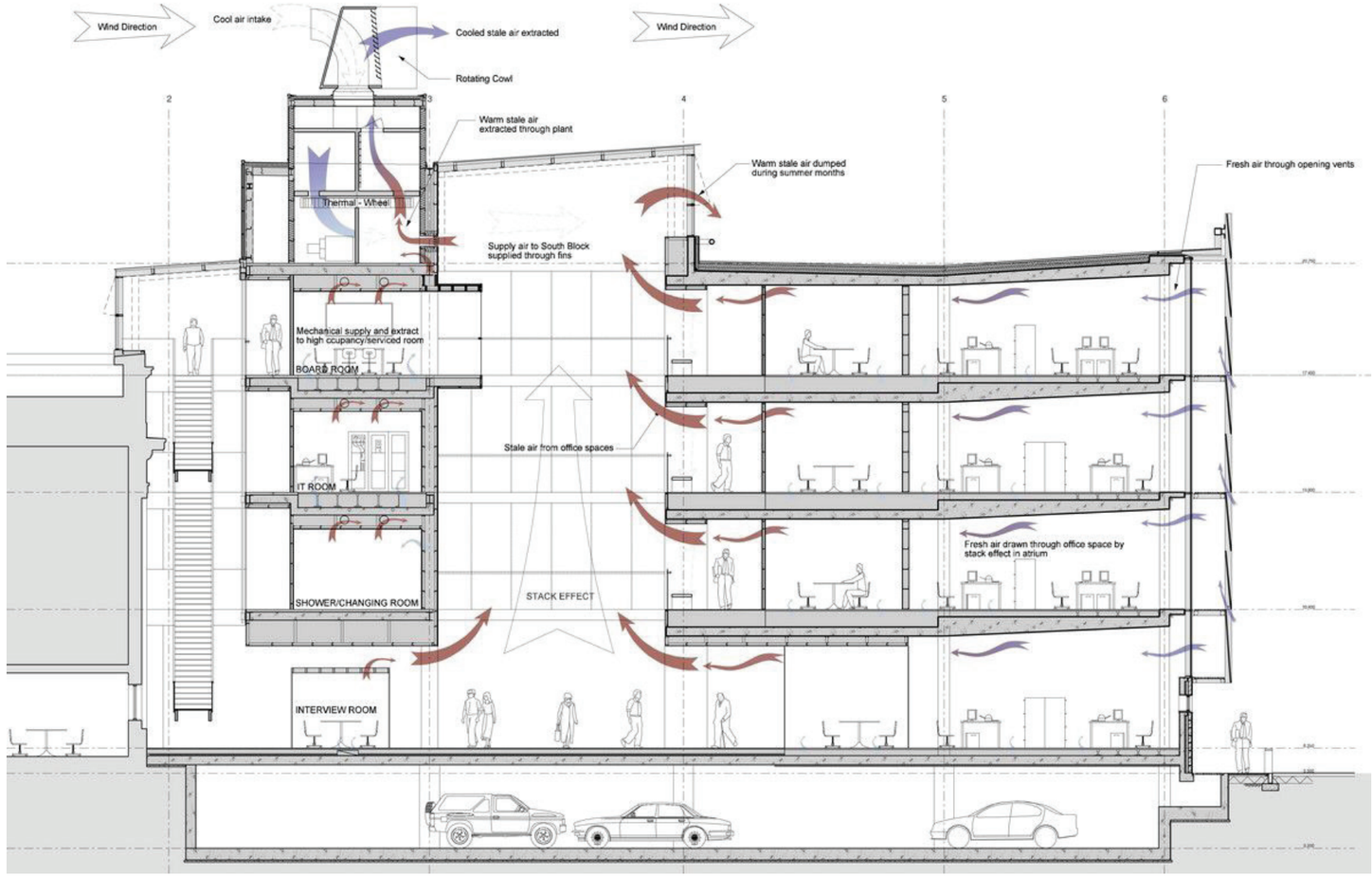
Basic Principles

Convection

A different type of convection occurs when the air is moved by a fan or by the wind, or when water is moved by a pump. When a fluid (gas or liquid) is circulated between hotter and cooler areas, heat will be transferred by the mechanisms known as **forced convection.**

(Source: Heating, Cooling, Lighting by Lechner)



Stack effect through atrium space releases warm air through roof while pulling in cool air from facade. Convection assisted by large rotating cowl and thermal wheel at high level.

Wind Cowls

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Radiation

The movement of heat through space (not air) as electromagnetic waves. The sun's energy reaches earth by radiation. All parts of the electromagnetic spectrum transfer radiant energy.

Sunlight (solar radiation), is a form of radiation that originated from the Sun. Sunlight that is incident upon the Earth's surface has been filtered through the atmosphere, with some of the ultraviolet radiation being absorbed. In addition to providing light for Earth, sunlight also acts as a source of radiant heat, warming the Earth.

When an object, or an assembly is warmed by radiant energy, the energy is absorbed into the material. All bodies facing an air space or a vacuum emit and absorb radiant energy continuously and since radiation is not affected by gravity, a body will radiate in all directions. Radiation is, however, affected by the nature of the material with which it interacts and especially the surface of the material.

(Sources: www.jlconline.com and Heating, Cooling, Lighting by Lechner)

Project: ENDESA Pavilion is a self-sufficient solar prototype. A facade composed by modular components, like solar brick(s), that respond to photovoltaic gain, solar protection, insulation, ventilation, and lighting. The facade responds to the solar path, being active and becoming permeable towards south, while becoming closed and protective towards north. The behavior of this skin makes visible the environmental and climatic processes that surrounds the prototype. - ArchDaily

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Radiation

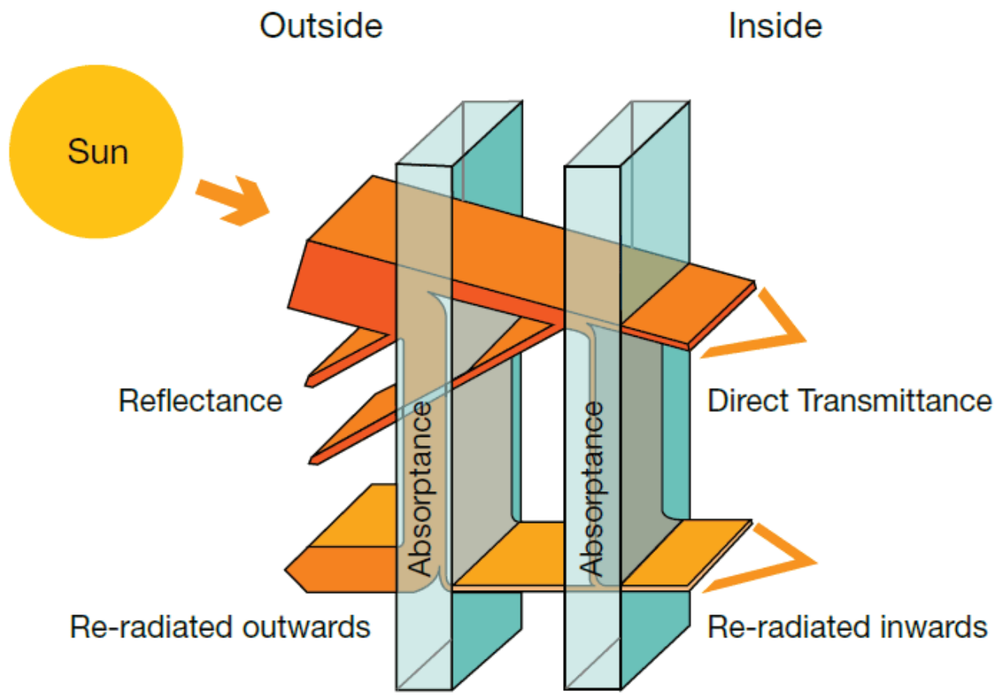
Transmittance - the situation in which radiation passes through the material (i.e., transparent or translucent).

Absorptance - the situation in which radiation is absorbed and converted into sensible heat within the material.

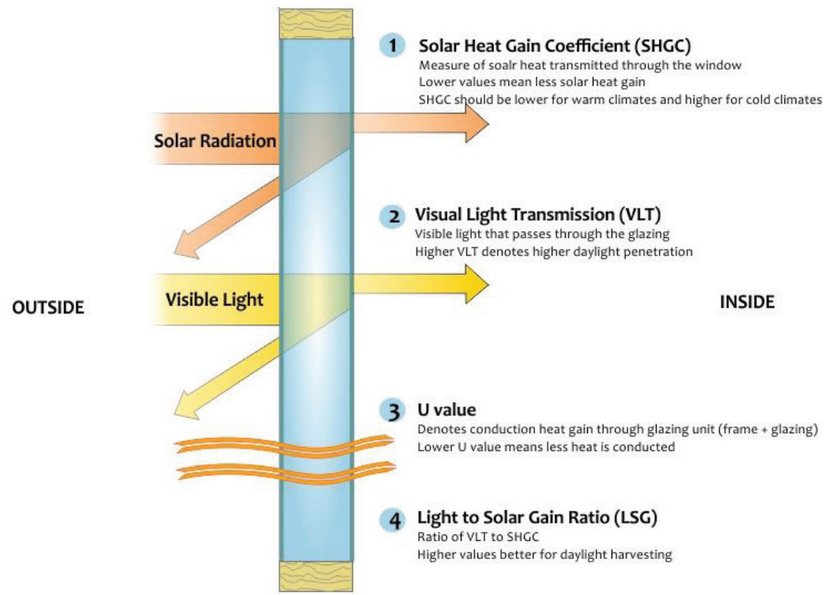
Reflectance - the situation in which radiation is reflected off the surface.

Emittance - the situation in which radiation is given off by the surface, thereby reducing the sensible heat content of the object.

(Source: Heating, Cooling, Lighting by Lechner)



(Source: https://www.pilkington.com/)



(Source: https://fairconditioning.org/)

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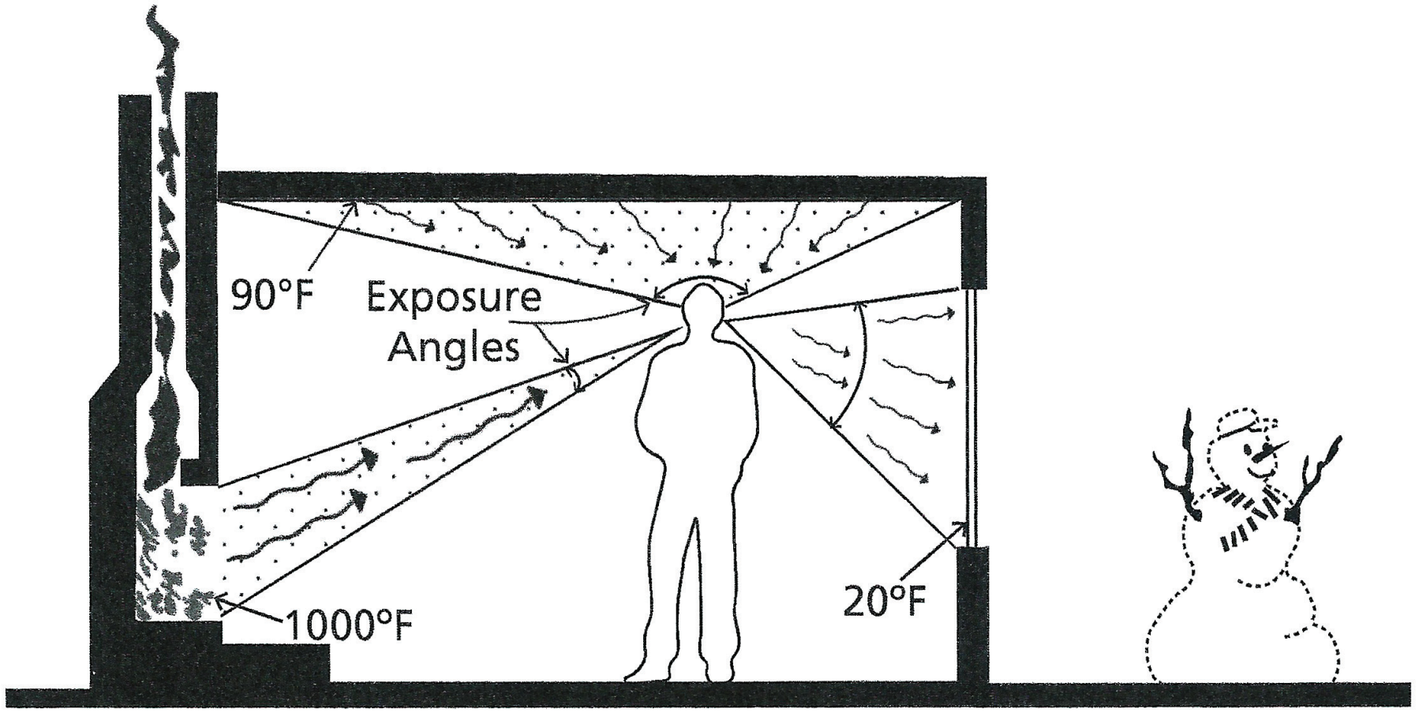
Mean Radiant Temperature

Mean Radiant Temperature (MRT) is the weighted average radiant temperature of a point in space, and it varies from point to point. The radiant heating or cooling effect of a surface is the product of the surface's temperature and its exposure angle.

Diagram: The radiant effect on one's face from a fireplace is quite high because the fire's temperature at ~ 1000F more than compensates for the small angel of it exposure. A radiant ceiling can have just as much warming effect but with a much lower temperature because its large area creates a large exposure angle. The radiant effect can also be negative, in the case of a person standing in front of a cold window.

(Source: Heating, Cooling, Lighting by Lechner)



The mean radiant temperature (MRT) at any point is the combined effect of the temperature and angle of exposure of all surfaces in view. For simplicity, the radiant effect from the walls and floors are not shown.

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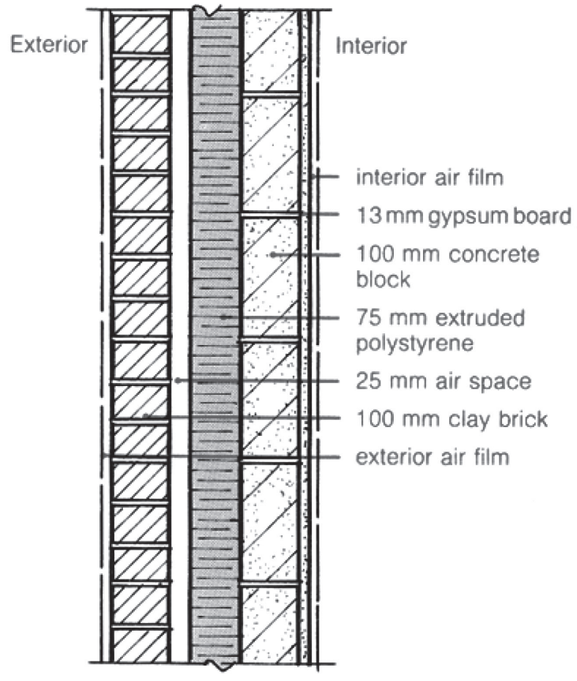
Thermal Resistance

The opposition of materials and air spaces to the flow of heat by conduction, convection, and radiation.

Thermal resistance in terms of **R-value**

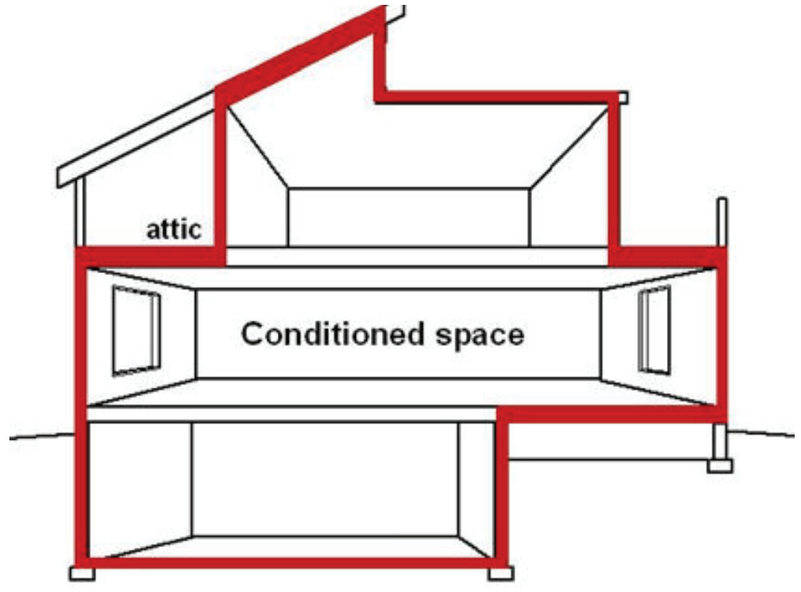
Heat-flow coefficient in terms of **U-value (U=1/Rt)**



component		R value ($m^2 \cdot °C/W$)
interior air film	—	0.120
gypsum board	—	0.081
concrete block	—	0.125
ext. polystyrene	—	2.603
air space	—	0.171
clay brick	—	0.074
exterior air film	—	0.030

$\lesssim R = 3.20\ m^2 \cdot °C/W$

The R-value for a wall is the sum of all of the R-values for all of the individual components PLUS values for inside/outside air films and air spaces



Building thermal envelope / Line of thermal resistance

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Basic Principles

Time / Thermal Lag

Thermal mass is a material's resistance to change in temperature and the ability to absorb and store heat energy. Thermal lag is the name given to the delay in the stored heat being released from the material as the ambient temperature decreases. So thermal mass is a material that stores energy and how long that energy is able to be stored as surrounding temperatures change is called thermal lag.

Materials with long thermal lag times (for example, brick, concrete, rammed earth) will absorb and release heat slowly.

(Source: www.onecommunityglobal.org)