Energy Efficient Architecture

Lecture 2

Heat Transfer

What is heat transfer? The transfer of heat is normally from a high temperature object to a lower temperature object. Heat transfer changes the internal energy of both systems involved according to the first law of thermodynamics. So heat transfer is just the temperature difference happens between two different objects with two different temperatures. So imagine there is a hot cup of milk in which it is poured over a cold cup. There is a constant temperature heat transfer that occurs between two i.e. liquid medium and the solid medium the cup which holds the milk. This heat transfer usually happens until it reaches the same temperature. This is called heat transfer. As you see in the image heat transfer happens in all these factors conduction, convection, radiation and evaporation. An example is greenhouse effect. It is the temperature difference between the two neighboring objects that causes this heat transfer. The heat transfer continues until the two objects have reached thermal equilibrium and is at the same temperature. So when there are two, as we said before when there is two objects with two different temperatures which is brought in contact with each other, the temperature and heat transfer happens until they meet the same temperature when they attain the equilibrium. Till then the heat transfer happens by the four different various categories conduction, convection, radiation and vaporization. Heat transfer always moves from a warmer place to a cooler place. Hot objects in a cooler room will cool to room temperature. When you are keeping hot pan with food prepared and when it is kept outside in a dining hall it usually cools down. This is because of the heat transfer which is happening from the hot pan to the surrounding cold environment. There is a constant temperature heat transfer which is happening to maintain the same temperature which is equivalent to room temperature. Cold objects in warmer room will heat up to room temperature. When you keep an ice cream outside, it usually melts. This happens because the room temperature is higher compared to the temperature of the ice cream. So it melts and becomes the same temperature as of the room.

Question is if a cup of coffee and a red Popsicle were left on the table in this room what would happen to them and why? If there is Popsicle which is an ice-cream and a hot coffee, what will happen is the cup of coffee will cool until it reaches room temperature. The Popsicle will melt and then the liquid will warm to room temperature. As we said before the ice cream melts down and it matches to the room temperature and the hot coffee also cools down to meet the same room temperature. This happens by heat transfer.

Heat Transfer Methods

Heat transfer methods are conduction, convection and radiation. Conduction is when you heat a metal strip at one end, the heat travels to the other end. as you see in this image, a metal strip is heated and the carbon atom which is present are being accelerated by heat and the heat which is

present here is being transferred through the metal strip which is making the carbon atom present even on the end. Even though they are not subjected to the direct heat, it starts moving and this process is due to conduction. As you heat the metal the particles vibrate, these vibrations make the adjacent particles vibrate, and so on and so on. The vibrations are passed along the metal and so is the heat. We call this conduction. When metals are different, the outer electrons of metal atom drift and free to move so when the metal is heated, this sea of electrons gain kinetic energy and transfer it throughout the metal. Why this happens is due to the kinetic energy which is being produced when you heat the metal strip. when you heat one end of the metal strip, the kinetic energy of the whole metal strip is being activated which makes the carbon atom which is present in the metal strip to vibrate and all the carbon atom to act on the same way which is being subjected to the heat at one end of the strip. Insulators such as wood and plastic do not have this sea of electrons which is why they do not conduct heat as well as metals. When you see, it is always good conductors or the ones which can conduct heat when considering insulators like wood or plastic does not have the same type of electronic atomic structure to it because of which it does not conduct well compared to the metal conductors which we saw in the previous example. Why does metal feel colder that wood if they are both at same temperature? Metal is a conductor, wood is an insulator. Metal conducts the heat away from your hands. Wood does not conduct the heat away from your hands as well as the metal. So the wood feels warmer than the metal. you must have observed two different metals which are kept at same room temperature whereas one is much colder, the metal and the other i.e. wood is not as cold as the metal even though the metal is kept at same room temperature, there is no heat transfer which is happening between these two objects because the property of these two elements are completely different and it does not allow the metal to become to the same temperature as the room or the wood to become the as cold as the metal strip.

Convection: what happens to the particles in a liquid or a gas when you heat them? Considering the particles to spread out and become less dense. First this is a liquid and then you heat them. Then it becomes more gaseous and the atoms which goes inside the fluid are becoming more loose which is making the overall substance move around freely as shown here. So this effect is called fluid movement. And what is a fluid? A liquid or gas.

Third method of heat transfer, how does heat energy get from the sun to the earth? When the sun is up in the morning we feel the heat by the sun. This has been affected by the earth by a process called radiation. There are no particles between the sun and the earth so it cannot travel by conduction or by convection. as we have seen in the earlier example there is carbon atom which is accelerating a certain kinetic energy because of which the metal strip is acting in the weight as shown and the energy has been transferred to one part of the element and to the other but whereas when you consider the overall earth atmosphere there is no particle like a metal strip which is connecting like a sun and our earth but still we are getting the heat radiation which is emitted by the sun it is not done by conduction or convection. It is by a process called radiation. Even the same happens by a human body. We lose heat and gain heat by the same process of

conduction, convection and radiation and because of which we sweat and we feel cold and everything. All these process happens because of all these physics of heat transfer. by respiration we are losing certain amount of heat loss and then radiation by external factors and convection and evaporation by sweating we are losing some energy by evaporation which is taken out by the air which is falling on our skin surface and then this is why you feel hot or cold in a room with certain temperature band and only within a certain temperature band you feel comfortable because all these factors will come to an equilibrium state only at that type of temperature and when you are exposed to that type of temperature and thermal comfort band.

Physics of Heat Loss

Physics of heat loss, for the body to remain at a constant temperature the metabolic heat produced must balance the heat lost by convection (air temperature, air speed), radiation (surface temperature), and evaporation (temperature, humidity and air speed), and conduction. So physics of heat loss of each individual body is also taking place on the same process as how it is happening in a metal conductor and insulators. the same process of maintaining constant temperature, these are again the factors acting on our body which is for example convection is the one which is maintaining our air temperature and air speed, and radiation because of which surface temperature of any material is being maintained so for example if there is instinct solar radiation which is falling through the window on a wooden surface or a carpet surface it gets heated because of the radiation which is falling on it which comes under radiation and evaporation is temperature, humidity and air speed so when we are exposed to higher metabolic rate like when you are in a gym or when you are working out or when you are lifting heavy weight you are sweating because there is some type of energy which you have been losing in form of calories which is coming out as sweat which is a process by which it happens evaporation. And again conduction, Conduction is heat transfer between external room temperature and body surface skin temperature.

Convective heat loss to the air depends on difference between the temperature of the skin or the surface of the clothes and the air temperature. Heat is lost by convection is still air-air near the body is heated and rises in a plume above the head. Rate of heat loss will be increased by air movement from windows or fans. as we are losing some type of energy on skin surface we should be maintaining constant air flow which is taking out the sweat which is forming on our skin surface so that even though we are losing some type of energy via evaporation which will be taking sweat taken out by the air flow and the wind directions by which you are going to orient your windows because of which you still feel comfortable even though you are sweating. So this is like a psychological effect which will be created to achieve thermal comfort.

Radiant heat exchange is heat transfer depends on the temperature difference between the building surfaces (radiant temperature) and the skin or clothing surfaces. Heat is lost to cold surfaces e.g. windows. Heat may be gained from hot surfaces such as radiators or from the sun which also heats the rest of the room. So in radiant heat exchange, this is like interaction between

human body and the surface we are surrounded in the environment. for example, if we have a room heater or room radiator in which the surface of the radiator will be very hot because there is constant hot water which has been circulated through the pipes and due to which there is a constant heat transfer between the colder room temperature and the hotter room radiator and there is constant interaction between these two temperatures till they attain the equilibrium so this type of process is happening because of heat exchange. So the same happens to the body, the impact of direct, diffuse and reflected solar radiation which depends on orientation of the individual relative to the radiation source. As you see, this surface is being reflected after getting the direct sunlight from the sun. There is some absorption and there is some reflection that has been happening. Since the human is exposed to direct sunlight, the body loses some type of heat by sweat and there is some diffusion of light which is happening in the surrounding atmosphere and environment. The thermal performance of a building refers to the process of modeling the energy transfer between a building and its surroundings. So now moving on to how heat transfer happens within the building so we are going to see how heat transfer happens between walls and roofs specifically. By the same methods of conduction, convection and radiation and depending on the different heat storage capacity of each material, the same process happens until each depending upon the object's atomic structure to attain its equilibrium. For a conditioned building it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made. so before starting to choose what type of heating, ventilation and air conditioning system that is going to be go with the built environment we must understand the heat loss and the heat gain which we are going within the built environment to choose appropriate and correct system to condition the building and to achieve thermal comfort. For example if you are having a room which is going to have a lot of different electronic equipment which is already radiating certain amount of heat energy to the built environment? So there is no point in adding more and more room radiators because there is already more of internal gain which is due to the electronic equipment. So how many numbers of hours they are used and how much number of people that are occupying, all these goes before choosing HVAC unit which makes it efficient to choose the same. For a non-conditioning building, it calculates temperature variation inside the building over a specified time and helps one to estimate the duration of uncomfortable periods. so the previous one that we talked about was for building which is conditioned using HVAC unit but there are lot of buildings which we don't use external systems to achieve the thermal comfort even for which calculating this is important because we can improve the design itself like increasing the window dimension and reducing the wall and window ratio which will make the design more efficient. Various heat exchange processes are possible between a building and the external environment. As you see, how humans are losing heat by radiant heat or by evaporation, the building also undergoes the same process by conduction, convection and radiation because of which it is absorbing some heat and releasing some heat loss which also has to be understood which happens different for different materials. As you see, this radiation is coming through the window because of this opening glass which has a property to let in the radiation that's falling on it but whereas when you consider the roof, the

radiation does not penetrate as good as what happens through the window or a glass. So it penetrates very little amount and maximum gets reflected. the same happens for an internal bulb or an air conditioning system that's been happening and this is the natural window open able which you can see there is constant heat transfer happening because the temperature within this built environment and outside is different which is been brought to equilibrium by the heat transfer that is happening by the process of convection. Heat flows by conduction through various building elements such as walls, roof, ceiling, floor, etc. Heat transfer also takes place from different surfaces by convection and radiation. As we said before it's the same process which is going on for different elements of roof, windows and floors everything has the same property which is contributing to the thermal comfort of the built environment. Besides, solar radiation is transmitted through transparent windows and is absorbed by the internal surfaces of the building. There may be evaporation of water resulting in a cooling effect. Heat is also added to the space due to the presence of human occupants and the use of lights and equipments. Not only just because of incident solar radiation that is falling on the window we are getting heat inside the building but it is also due to the presence of human beings and electrical equipments like tube lights and computers and other electronic equipments so you can feel a vast difference when a small room is occupied by one person whereas the same room with same dimension and same volume which is being occupied by 10 users. So the room which is occupied by 10 users will be much warmer compared to the room which is occupied by one user. This difference is mainly due to the human being also are emitting certain amount of heat to the environment which is adding to the thermal comfort or reducing the thermal comfort when we are in a hotter region. The body exchanges heat with its surroundings by convection, radiation, evaporation and conduction. If heat is lost, one feels cool. The thermal performance of a building depends on a large number of factors. they can be summarized as design variables (geometrical dimensions of building elements such as walls, roof and windows, orientation, shading devices, etc.) the thermal performance of a building is due to lot of different factors which goes in making the built environment such as orientation, shading, wall to window ratio and what type of glacing we are using, everything contributes to the heat transfer and gaining or losing the same. Material property (density, specific heat, thermal conductivity, transmissivity, etc.) so each material has different heat storage capacity according to the climate in which we are going to design and according to the need of the building or the thermal comfort to be maintained. This has to be chose accordingly. for example, when you are designing for a colder climate and if there is orienting your building towards solar radiation, direction then it is very ideal to have surface which has high thermal mass which has good heat storage capacity so it can absorb the heat from incident solar radiation which can trap inside it and it can be used for enhancing the human thermal comfort. Weather data (solar radiation, ambient temperature, wind speed, humidity, etc.). So you also need to know the local weather data which can be collected which can give informed decisions about where to place the window, to get benefited out of or completely ignore solar radiation, ambient temperature and humidity. So to achieve good quality air inside the environment we need to maintain certain air temperature and humidity levels to feel comfortable.

To achieve all these we need to know about what actually the scenario is around our surroundings. Only then we have to increase or decrease or maintain the same level as what it is present. A building's usage data (internal gains due to occupants, lighting and equipment, air exchanges, etc). In a building, how many people are going to use this room and what is the occupancy time if it is the school it is only being used from 9am to 4pm in the evening and the rest of the time it is going to be closed completely. So how to maintain the heat which is completely present or if it is a hotter country, how to get rid of this heat and what type of equipment is going to go inside. If they are going to have how many number of lights or fans which is going to contribute the heat. All these things have to be analyzed before to choose ideal conditioning systems for the building. To understand the process of heat conduction, convection and radiation occurring in a building, consider a wall having one surface exposed to solar radiation and the other surface facing a room. In this image it is a cross section of a wall in which one side is being exposed to direct solar radiation and one side which is built inside the built environment. So as you see, the solar radiation which falls on external surface, some gets reflected and some goes in the form of conduction. And there is constant temperature difference between which is present inside the room and the surface of the wall. Due to the temperature difference there is constant convection process which is happening by long wave radiation to make this wall on the same temperature as the room temperature. some of the radiation which is falling is also gets absorbed and some is being reflected and been sent by convection.

Heat transfer in roof, as we saw before this is what happens in wall and now when we absorb the roof, for some of the climate, for example regions with lower altitude like tropical location regions have lot of solar radiations on the horizontal surface say roof traps lot of heat radiation. To understand the physics of heat loss and heat transfer we must also know about how much heat conductivity and thermal resistant the material that we are choosing for the roof also has and how does the heat transfer from the roof to the built environment. So let's see in this picture, your home with radiant barrier. If there is pink band as radiant barrier. So when there is a barrier, the incident solar radiation gets deflected and whatever the small amount which also goes in due to the presence of barrier which gets circulated with this. As you see in this picture, this can be used beneficial for the places which have high solar radiation. we can use some type of solar barrier to eliminate ourselves from direct solar radiation which is falling on the roof and to avoid from the process of convection and to achieve the thermal equilibrium we have to install a specific layer to avoid this happening. but when your home is without radiant barrier when there is no radiant barrier, because of thermal heat transfer that is achieved through thermal equilibrium for the two surfaces to achieve the same temperature, it is constant heat transfer that is happening between the temperature and the surface of the roof because of without any barrier, this is how it happens. So when you are having colder climate but with good solar radiation, this can be used to take advantage of the incident solar radiation.