Course Name: Bioclimatic Architecture: Futureproofing with Simple and Advanced Passive Strategies

Professor: Dr. Iyer Vijayalaxmi Kasinath

Department of Architecture,

School of Planning and Architecture, Vijayawada

Week: 07

Lecture 02

Thermal Mass and Night Flushing

Hello everyone, welcome to another session on advanced passive strategies. So today's advanced passive strategy will be thermal mass. Now thermal mass is a very good technique that can be used, especially in cold climates or hot and dry climates. This can be a very good technique that can be used to enhance indoor comfort. So, thermal mass is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks, and tiles.

They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass. Appropriate use of thermal mass throughout the home can make a big difference to comfort and heating and cooling builds. Objects with high thermal mass absorb and retain heat.

Thermal mass is crucial to good passive solar heating design, especially in locations that have large swings of temperature from day to night. Objects with high thermal mass absorb and retain heat, slowing the rate at which the sun heats a space and the rate at which a space loses heat when the sun is gone. Without thermal mass, heat that has entered a space will simply re-radiate back quickly, making the space overly hot without sunlight and overly cold in the absence of sunlight. Thermal mass actually acts like a thermal battery. During summer, it absorbs heat during the day and releases it by night to cooling breezes or clear night skies, keeping the house comfortable.

In winter, the same thermal mass can store the heat from the sun or heaters to release it at night, helping the home to stay warm. Thermal mass is not a substitute for insulation. Thermal mass stores and releases heat, and it depends on the material that we are talking about. Insulation stops heat flowing into or out of the building. A high thermal mass material is not generally a good thermal insulator.

For example, rammed earth. Thermal mass is particularly beneficial where there is a big difference between day and night outdoor temperature, which is called diurnal variation. The correct use of thermal mass can delay heat flow through the building envelope by as much as 10 to 12 hours, producing a warmer house at night in winter and a cooler house during the day in summer. An appropriate thermal lag must be considered when we try to design a house with an appropriate thermal mass. Appropriate thermal lag is the rate at which heat is absorbed and re-released by uninsulated materials.

Lag is dependent on conductivity, thickness, insulation levels, and temperature differences on either side of the wall. Consideration of lag times is important when designing thermal mass, especially with thick, uninsulated external wall systems like rammed earth, mud brick, or rock. So, if you have When you have the outdoor temperature like this, this is T outdoor and then you have the light timber framed structure. You can see the light timber-framed structure follows the temperature pattern of the outdoor ambient air. Then you have a heavy building with external insulation.

Now my guess would be that this time would be somewhere around 12 noon. Let us consider this as 12 noon. And this is the noon of the next day. And let us just theoretically consider this as midnight. And then look at the heavy building set into a partially covered earth.

Look at the temperature here. You can see that the heavy building set into and partially covered with earth which is called as earth burming. That building has almost a constant temperature with almost no relevance to what is happening on the outside. Now if you look at the time lag, this is the difference between the light-framed building and the outdoors. And this is the temperature difference between the heavy building with external insulation.

So, from this, you can see how the time lag varies based on the material that is used. For light timber frames, the time lag is very less. Now let us consider this graph. In this graph, you can see that this is the temperature outside. You can see this is supposedly the indoor air temperature of a light-framed building.

Look at the time lag. I am, for the sake of convenience, assuming this is 12 noon and the highest peak outside is happening at 12 noon. I am just considering that. You can see that the time lag of the light-framed timber is minimal. heavy building with external insulation now if you look at the time lag, the time when the peak of temperature happens inside the room of a heavy building with external insulation as compared to the peak of the outside ambient air and if you consider this as midnight, then this should be about 3 noon 3 o'clock, which is 15 hours so you can see this is the time lag for a heavy building with external insulation Now consider this case of a building which is a heavy building set into and partially covered with earth, which is nothing but an earth-burnt structure.

You can see that the building is almost flat. I am not even able to find out where it is peaking, but even if I assume the peak is here, as compared to the peak outside, then you can see this is the time lag. So just see how time lag varies with varying building materials. What is the concept of thermal mass in winter? So here you allow the thermal mass to absorb heat during the day from direct sunlight or from a radiant heater. It reradiates this warmth back into the home throughout the night.

By alternately storing and releasing heat, high thermal mass smooths out the extremes in daytime temperature. In warm or hot climates where there is significant temperature variation between day and night, also called diurnal variation, heat is absorbed during the day and then released in the evening, when the excess can be either flushed out through nocturnal air ventilation or it can be used to heat the space at the outside temperature drops. The entire process can thus be repeated the next day. Because thermal mass distinguishes itself as a tool for dampening temperature amplitudes, it works best when excessive heat builds up and requires absorption and much later disposal. For example, where the excessive heat generated by solar gain is absorbed by the building fabric during daylight hours or where a particular environment has excess heat that is generated by the people who stay inside and absorbed by emission into a cooler nighttime space.

So, in winter, how can you use thermal masses? You allow the solar radiation to enter the house. This solar radiation heats up the room and the envelope, or the surfaces, which are basically the wall. and the floor, then since it is cold outside, what you do is at night you close the windows, and whatever was absorbed by the floor and the walls is radiated back into the room, keeping the room warm during winters. During daytime again, you open the window and allow the sunshine to enter in and the solar radiation will again Keep the walls warm. Again, close the window in the evening.

When the outside is cold, the inside will be warm. So this heat, which is stored by the envelope, which is basically walls and floor to some extent, roof also. is again released provided you close the window. All the openings should be closed as you trap the heat. Now how does it function in summer? In summer, what happens is you allow the cool night breeze or the convection currents to pass over the thermal mass.

This draws out all the stored energy. So, what you actually do is you know very well that when you allow the solar radiation to fall on the floor, the floor and the wall absorb the solar radiation and heat the wall. It heats the wall and floor. At night, what you do is keep the windows open.

Do not close it. Allow the breeze to flow, and whatever solar radiation is released back by the envelope gets flushed out. So heat is released. Now, what can be, and how else can thermal mass be used? Suppose you have a thick wall. Solar radiation strikes on the wall. When solar radiation strikes, the first layer of the wall gets heated.

This transfers the heat on this side and this side of the wall. Then the second layer gets heated which depends on the thermal capacity of the material. It further transfers on both sides. Further, the next layer gets heated. It transfers on either side and so on and this continues all through the day now, supposing again this layer transfers the heat on either side Now, for example, supposing by then the evening happens, what happens? This layer gets cooled Let me indicate it with green layer This layer gets cooled So, heat radiation along the outside is faster.

So, now the direction of heat gets reversed. So, can you see by virtue of designing this wall, which is thick, you have not allowed the heat to reach the inside at all? The heat does not reach inside at all, and therefore the indoors remain at indoor temperature; what happens remains constant. Because the outside heat has not entered inside through the wall. I am talking only about through the wall. I am not talking of, you know, somebody opening the door, going in, coming out hot air draft, getting inside.

I am not talking of that. The heat component because of the thermal mass can be cut drastically if you are able to choose the correct walling material. in the correct climate. For Jaisalmer, how much should it be, and for Delhi, how much should it be, so that the indoor temperature can be maintained fairly constant. So, use of high-mass construction is generally not recommended in a hot and humid climate. due to their limited diurnal range.

Passive cooling in this climate is usually more effective in low-mass buildings. Thermal comfort during sleeping hours is a primary design consideration in tropical climates. Lightweight construction responds quickly to cooling breezes, and high mass can completely negate these benefits by slowly re-releasing heat absorbed during the day. What should you do in warm, humid, or warm and mild temperate climates? The predominant requirement for cooling in these climates is often suited to lightweight, low-mass construction. High-mass construction is also appropriate but requires very sound passive design to avoid overheating in summer.

In multi-level design, high-mass construction should ideally be used on lower levels to stabilize temperatures. Low mass on the upper levels ensures that as hot air rises through convective ventilation, it is not stored in the upper levels as it leaves the building. This is particularly important if sleeping spaces are located on upper levels. Ground and first floor spaces should be capable of zoning or closing off to prevent temperature stratification in winter. In cool temperate and alpine climates, winter heating is the main need in these climates, although some summer cooling is generally required.

Ceiling fans usually provide adequate cooling in this low-humidity climate. High mass construction combined with sound passive solar design and a high level of insulation is an ideal solution. Good solar access is required in winter to heat the thermal mass. What happens in a hot, dry climate? Both winter heating and summer cooling are very important in these climates. High-mass construction combined with sound passive heating and cooling principles is the most effective and economical means of maintaining thermal comfort.

Diurnal ranges are generally quite significant and can be extreme. High mass construction with a high insulation level is ideal in these conditions. Let us look at the thermal mass checklist. The simple rules of thumb set out here determine appropriate thermal mass levels in different climate zones. Heating dominated temperate and cold climates, cooling dominated temperate climates, and heating dominated climates with no northerly solar axis.

Mass levels vary according to a solar axis, which has a direct relationship to glazing type, building orientation, area, and shading. Second is cool breeze and cool night access, including mechanical. Third is diffuse and ambient heat gains in summer. Fourth is nighttime sleeping comfort. Fifth are occupation patterns and heating or cooling system use.

Sixth is seasonal extremes of climate zone. Seventh is the average diurnal range as a useful indicator of appropriate thermal mass levels in a house. Eighth, low-mass construction generally performs best when diurnal ranges are consistently 6 degrees centigrade or less. Coastal, temperate climate, warm and humid—these are the most appropriate climate types. Moderate mass is best for 6 degrees to 10 degrees diurnal range. Slab on the ground, lightweight walls such as brick veneer.

Whereas high mass construction is desirable for a diurnal range of above 10 degrees centigrade like slab on ground and some or all high mass walls. Then how do we use thermal mass effectively? Thermal mass is most appropriate in climates with a large diurnal temperature range. Why do we say that? Because, as we had already seen, when you have high diurnal range and you have a thick wall or a wall that has high thermal mass, two things can happen. Let me demonstrate here that you have a thick wall and diurnal variation. Say let us look at a variation of 10 degrees or 12 degrees.

So, during the day the temperature is 35 degrees Celsius, and at night it is 25 degrees or 23 degrees Celsius. Suppose you keep the window open and you allow the solar radiation inside. When it is 35 degrees Celsius, let us assume the indoor temperature reaches 30 degrees Celsius. At night, what will you do? You will open the windows and allow breeze, which is at 23 degrees Celsius, to enter inside a room, which is 30 degrees Celsius. Now, what will it do? It will ensure that the indoor becomes, say, probably 27 degrees Celsius, but having a high thermal mass wall, which further aids in keeping the indoor cool, will reduce the temperature to 25 degrees Celsius.

How will the wall aid in reducing the indoor temperature? How does the thermal mass play? What role does it play? That is where I said, assuming this is the wall and assuming solar radiation falls on the wall. If you see, assuming solar radiation strikes the wall, the first layer of air gets heated up. Suppose the solar radiation strikes at 35 degrees Celsius. The first layer of air gets heated up, which passes the heat to the first layer of the wall. The first layer of the wall passes the heat inside, and the heat also radiates on the outside.

The second layer of the wall gets heated up based on its thermal capacity, and that transfers the heat and passes on the heat on the inside and outside. When I say outside to the adjacent only to the adjacent layer. Then further this layer gets heated up. It passes the heat on the next layer and the adjacent layer, and so on and so forth and so on and so forth.

By then, what happens? Evening. Evening, what happens? This 35 degree becomes, say, 30 degree or 28 degree. Which means this wall is now going to only radiate outside. So each of the layers will only keep radiating towards the outside, and there is no heat radiated on the inside. And therefore, the indoors will remain cool.

This is the concept of using the thermal mask. So in cool or cold climates. Where supplementary heating is often used, houses benefit from high mass construction irrespective of diurnal range. In tropical climates with diurnal range, high mass construction can cause thermal discomfort. unless carefully designed, well shaded, and insulated. So always use thermal mass in conjunction with sound climate-appropriate passive design and knowledge of the climate of the place and the thermal mass of the building material that you use.

So when we talk of thermal mass, it's very important for us to understand that a nocturnal ventilated cooling clubbed with thermal mass can be a very effective passive cooling tool. So, in this section we will look at night flushing or nocturnal ventilated cooling as a passive cooling technique. So, what is night ventilation? Now, it is a known fact that the nighttime temperature of any place is lower than the daytime temperature. Night ventilation, night flushing, night purging, or nocturnal ventilative cooling.

These are all the same things. And it is a strategy that uses the natural lowering of temperature that occurs at night. It is a passive cooling strategy that utilizes the natural drop in temperature after sunset to remove the accumulated heat within a building's thermal mass. So why should we use this, and how is it used? This is used to maximize the efficiency of the building's ventilation system. and to have refreshing internal spaces ready for next day.

This can be done with mechanical fans. Many buildings use natural ventilation systems, allowing them to exhaust the high volume of stale air with very little energy demand. Why should we use night flush? This is important. During the day, the building is occupied by people, which leads to worsening indoor air quality. So the indoor air quality becomes poor because of the buildup of carbon dioxide and carbon monoxide from breathing. Besides, there are contraptions such as computers and machinery that build heat.

This heat is absorbed into the building's surfaces and structure. Night flush helps to partly remove this air. Let us look at the working principle of night ventilation. Night cooling uses the principles of natural ventilation, either wind-driven or thermal buoyancy, to allow the warm, stale air to be replaced by cool outdoor night air. This enables the room to have fresh air, and the building mass is also cooled.

In this process, the vents are opened for a definite period of time during the night when the building is not occupied and no one will be affected by the cold drafts. Then these are closed again in time for the building to return to a comfortable temperature before the occupiers return to the building. So in this concept, at night the buildings are openings are all opened up for cool air to enter the building. The cool air that enters the building lowers the temperature of the indoor air, and that is absorbed by the internal surfaces. And as I have already been telling you, warm air rises up and escapes and cool air retains.

And during the day, this must be closed. All the vents must be closed so that the cool air is trapped inside. Now for night flush to be most effective, the building should be completely closed or sealed from outside during the day. This prevents the building from gaining excess outdoor solar air. Because the hotter the building during the day, the more difficult it is to cool at night. You must try to flush the thermal mass with the cool outdoor air, enabling the thermal mass of the building to lose its heat and become cool through the night.

So during the day, a lot of heat is generated either by human beings who radiate a lot of heat or by contraptions like computers or machines, which radiate a lot of heat. That gets absorbed by the walls of the walls, floors, roof, and thermal mass of the building. So during the day the room becomes the house or the space becomes very hot. At night, when the temperature dips outside, you open all the vents and allow cool air to enter in. All the heat that is absorbed by the thermal mass gets radiated back to the atmosphere, and the room becomes cool.

In this process, the hot air also escapes because hot air is light in weight and always rises. Baving way for cooler air. Baving way for cool air. And therefore, the room becomes cool by morning.

At that time what should you do? You should close all the openings. So the inside becomes cool; the inside remains cool during the day. And in the evening again, as the people and the contractions would have radiated the heat. And the indoors become warm during the evening. Again, open the window at night and continue this cycle. So how does night flush work? So how does night flush work? Night flushing works by opening up pathways for wind ventilation and stack ventilation throughout the night to cool down the thermal mass of the building by convection, which means the building must have a considerable thermal mass.

Only then will this technique be effective. Early in the morning, the building is closed and kept sealed throughout the day to prevent warm outside air from entering. During the day, the cool mass absorbs heat from occupants and other internal loads. This is done largely by radiation, but convection and conduction also play important roles. What are the benefits of natural night cooling? First is energy efficiency. One of the biggest benefits of passive night cooling strategies using natural ventilation is that it is an energy efficient way of cooling the building as it does not rely on any mechanical fans or devices or temperature control.

This in turn helps to reduce energy costs and improves the building's environmental performance. Second, it is draftless, which means additionally carrying out the cooling process overnight not only ensures that only cool air is circulated, but there is no risk of cool and cold drafts or no noise because of any contraption. Third, it's a very safe method. It is a non-toxic method.

It is a non-toxic method. And fourth, you do not use any other equipment. It happens just because of the natural forces of heat transfer. Now let us look at the limitations and constraints. Night cooling is only suitable for climates where temperature overnight is considerably lower than in the day. So night cooling is effective only when the overnight temperature is considerably lower than in the day and is typically used during summer months, which means what does it mean? The diurnal variation must be large.

Then it is very effective. So high diurnal variations are needed. The air at night must be clean. That is, there should not be a place where there is a sandstorm or, you know, a lot of suspended particles. Then, if you open the window, all the sand and the suspended particles will come in, making the people unhealthy. Wind and rain protection of the vents is needed to protect the building indoors from any damage. Then fifth, adequate barriers are needed for safety and security of the indoors, especially in residential buildings or buildings occupied during the night.

And buildings that host priced equipment and machinery. Sixth, wind-induced ventilation of buildings is greatly influenced by surrounding buildings. So if there are too many adjacent buildings that do not permit cool breezes to enter the building, then ventilative cooling, night ventilative cooling, or night flushing will not be effective. Then usability can be a concern, as the opening and closing of all the windows can be very tiresome for the occupants or maintenance staff, and they may not always open and close everything at the optimal time. Now this can be resolved by having mechanized windows, or, you know, ventilation louvers, controlled by either a timer or a thermostat-driven control system.

Or you also have. You know you have these kinds of lures. Or this kind of shade, which is in part. And they have a central connecting timber.

And if you pull this down. The entire system. No, this thing opens. The louvers open. And if you push it up.

Then this flap comes down. And you get. A closed window. So you can. It's up to you. You are an architect.

You are a designer. It is up to you. How you design it. Even mechanically. Or manually. So the best combination would be. Thermal mass. Plus. night flushing. So if used effectively with an understanding of thermal mass, night flushing can shift the indoor temperature closer to the comfort zone.

So if you have the external temperature swing like this, then you can make the indoor temperature swing in such a way that it lies within the comfort band. So when is this useful? So night purge ventilation or night flushing keeps windows and other passive ventilation openings closed during the day but open at night to flush warm air out of the building and cool thermal mass for the next day. So night purge ventilation is useful when daytime air temperature is so high that bringing unconditioned air into the building would not cool people down but where nighttime air is cool or cold. This strategy can provide passive ventilation in weather that might normally be considered too hot for it. Successful night purge ventilation is determined by how much heat energy is removed from the building by bringing in nighttime air without using active HVAC cooling and ventilation.

Now let us look at a study that was done by Wu Hong and his other colleagues. On investigating night flushing potential in a multi-story open-plan office in Germany. Using Trinlizard with Transis 18. This office building was assumed to be located in Germany.

With a high facade glazing. So this is the facade or the model of the building. On which analysis was done. for night ventilation for passive cooling through simulation to assess the benefits of night flush. So to investigate the impact of night ventilation, the three cases were studied. What happens if the building is fully mechanically ventilated and conditioned? This is called the base reference case against which the results of the other cases are compared.

Second is naturally ventilated at night when there is no occupancy. The impact of wind-driven ventilation is ignored. And third is naturally ventilated at night with wind included. It is demonstrated that nighttime ventilation in an open office with a central atrium offers considerable savings in annual operational energy costs for cooling as well as initial investment costs by reducing equipment sizing. In the case of the location Regensburg in Germany, annual cooling and peak cooling demand were considerably reduced by 55% and 15% compared to the benchmark building, which is what was normally built in that place It was found that natural ventilation without wind brought down the annual cooling energy from 20.6 to 9.3 kilowatt hour per square meter. And due to nocturnal ventilation cooling, you can find that there was a dramatic reduction in the annual cooling load. From 20.6 it went to 8.9, which is a considerable reduction in the cooling load. Another study on the effectiveness of mass and night ventilation in lowering the indoor daytime temperature was done by Baruch Givoni.

So he took three buildings with the same heat loss coefficient but with different mass levels. So, we will look only at a low-mass building, which was primarily conventional stud wall construction used in that place, and a high-mass building, which is an insulated concrete wall. They were monitored in a summer month at a place near Pala in San Diego. The results showed that the indoor maximum temperature of a low-mass building was very close to the outdoor maximum except during days with a sharp rise in the outdoor maximum. So if this is the outdoor maximum, you see, this is the outdoor maximum or dry bulb temperature of that place, then it followed this low-mass building, followed the dry bulb temperature of the outside very closely.

During the cooler days, the indoor maximum was even above the outdoors in spite of night ventilation. But in the case of high-mass buildings, the night ventilation has lowered the indoor maximum temperature consistently below the outdoor maximum. So you can see how consistently for every day the maximum temperature in a high-mass building is always lower than the outdoor dry bulb temperature. Therefore, one of the big players in the success of night flush is having a high thermal mass, which is extremely important in the efficacy of night flush, and of course you must have high diurnal variation. So any place which has very high diurnal variations and where you have a high thermal mass In that place, night ventilation is a very effective indoor passive cooling technique.

So what are the materials with high thermal mass? They are water. Water has the highest volumetric heat capacity of all commonly used materials. And therefore, we use it even in water walls. You remember the trombe wall and water wall class.

In this class or lecture, this concept would have been mentioned by me. Second is concrete. The third is clay bricks. Insulated concrete panels also have very high thermal mass. A brick has high thermal mass.

Earth has high thermal mass. And this concept is used in the earthen burming of structures. Earth burming or earth sheltering. Then natural rock or stone. So this thermal mass allows a log home to hold heat better in colder weather and to better retain its cooler temperature in hotter weather. And the new age material is phase change material. So I have just given a glimpse of a comparison of the properties of commonly used materials to understand their thermal storage capacity.

So reinforced concrete, brick, and stone have high thermal storage capacity. While thermal insulation has very poor storage. thermal, I mean heat storage capacity, and you can see hollow clay brick also has low thermal mass compared to solid bricks. Another study by Mohd Arif Kamal on the study of thermal mass as a passive design technique for building comfort and energy efficiency was done. And in that study it was found that if this is the outdoor air for a light structure, the temperature inside a indoor air light structure was always higher than the outdoor air and the indoor air of a heavy structure or a structure which has high thermal mass was lower than the outdoor air. You can also see that the time lag, which is the time difference between when the outdoor reaches its maximum and when the indoor reaches its maximum, is shifted greatly when you have a high thermal mass wall.

When you have a high thermal mass wall, two things happen. One is there is a shift in time lag, and it is effective for night ventilation. So this study concluded that there is no single material that has all the desirable structure and thermal properties. Combinations of materials with different properties are used to provide the necessary properties in an element. In order to be effective as a thermal mass, a material must have a high heat capacity, a moderate conductance, and a moderate density with high emissivities. It is also important that the material serves a functional purpose that is structural as well as decorative in a building.

Among common building materials, wood does not make a good thermal mass because it not only has low heat storage potential but is also not very good in terms of its conductivity. Rand earth provides excellent thermal mass because of its high density and the high specific heat capacity of the soil used in its construction. Concrete and other masonry products are ideal as they have high capacity for heat storage and moderate conductance that allows heat to be transferred deep into the material for storage. When sized properly, concrete is effective in managing diurnal energy flow, and it is also convenient to have structural concrete as it has thermal mass.

Insulating concrete forms are commonly used to provide thermal mass to building structures. Water is also an effective thermal mass in that it has high potential for heat storage, and it can be effective in a diurnal thermal management scheme. Steel, while having a seemingly high potential for heat storage, has two major drawbacks. Its low emissivity indicates that a large majority of the incident radiation is reflected rather than absorbed and stored. And its high conductivity signals a quick ability to transfer heat stored in the material's core to the surface for release to the environment, thus shortening the storage cycle to minutes rather than hours, which is needed for diurnal thermal tempering. Glass also seems to have a high potential for heat storage, but it is relatively transparent to near-infrared radiation and reflective to far-infrared radiation.

Adding pigments to glass, such as blue and green, increases its ability to absorb radiation, which can become a thermal problem during the cooling season. So, this study has clearly shown what materials are advantages as a combination of a thermal mass and nocturnal ventilative cooling by virtue of the material properties. So, in this lecture we saw how thermal mass and nocturnal ventilative cooling as a combination can form a very effective passive cooling strategy. So, we will stop today's class with this, and we will continue next class with another passive strategy. Thank you.