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

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Lecture 04

Hello everyone. Today we will look at one of the basic concepts based on which many other advanced passive techniques have evolved. And today we will see the trombe wall as a passive design element used for heating. among the different passive solar systems. Solar walls and trombe walls are currently the most popular due to their simple design and ability to be used in a variety of climatic conditions. The idea of a trombe wall is to use the empty space to store energy.

This system was developed by Felix Trombe in the 1950s and was first implemented in the south of France. Due to the thin airspace behind the storage wall, solar radiation is absorbed and accumulated as heat in the thermal mass. Then the heat is circulated as a result of radiating it directly into the building. Trombe walls are a special type of solar wall.

They are additionally equipped with vents at the top and bottom, which provide the thermocirculation of air between the indoor environment and the air gap. In this type of construction, heat exchange with the indoor environment is achieved both by transmission as well as ventilation through its vents. The solar radiation control is provided by the shading devices. The trombe wall is a well-known example where incident solar radiation on the system is captured by its absorbent surface and stored by means of its high thermal mass. After conduction, the thermal energy passes through the wall and is then released into the interior through convection.

The long-wave radiation from the internal surface and air thermocirculation. The latter is controlled by appropriately activating vents and takes place in an air gap created between a huge wall and a glazed facade that is intended to prevent long-wave radiation from the outside wall surface to the external environment. The adjacent room receives the thermal energy from the air flow rate that is heated in the air gap due to thermal circulation. Generally speaking, thermal circulation is important because, in some conditions, an air flow inversion may exacerbate the heat losses. Let us look at its working principle.

In the winter mode during the day, some of the heat that has accumulated in the area between the windows is directly released into the environment through the vents, while the other portion is retained by the mask. After limiting heat dispersion during the night by shutting the adjustable vent, the wall returns the heat that was accumulated by the radiation. In the summer mode, the mass accumulates internal heat during the day. But at night the heat is released outside, and the wall absorbs heat from the inside due to the radiation, causing the temperature to drop. Summarizing the purpose of the accumulation layer during the period of low outside air temperature is to use the accumulated thermal energy obtained from the solar radiation and then transfer it to an adjacent room in a period of low temperatures.

On the other hand, during a period of high outside air temperature, the task of the accumulation layer is to stabilize the temperature of the inside air, protecting the room from overheating. The main advantage of this type of wall is the ability to stabilize the indoor air temperature in the adjacent room. This is caused by the high thermal capacity of the accumulation layer. Due to the high weight of this layer, collector storage walls are mostly used in buildings with monolithic reinforced concrete or masonry walls. Let us look at the characteristics of the trombe wall.

Trombe walls are good at capturing solar energy because of their features and design. The following are the essential features of a trombe wall. First is the orientation. Trombe walls are often positioned to face the sun, maximizing solar exposure. They are frequently faced south in the northern hemisphere to receive sunshine all day long.

The second is the thermal mass. High thermal mass materials such as adobe, stone, or concrete can absorb and store a lot of heat. These materials are used in the construction of the trombe wall. Third is the dark absorptive surface. To optimize the absorption of solar radiation, the trombe wall's outer surface is made to be both dark and absorbent.

This assists in transforming solar energy into thermal energy. Then fourth are the ventilation openings. There is a space or gap between the trombe wall and the interior living space. This space allows for natural convection of air to circulate between the wall and the room. These are the vents.

Fifth is insulation. To reduce heat loss to the outside during times when there is no sunlight, like at night or on a cloudy day, the trombe wall is frequently well insulated. Sixth is glazing. Glass or polycarbonate are two transparent glazing materials that are used on the south-facing side of the trombe wall. This glazing allows sunlight to enter while preventing heat loss.

Seventh is thermal storage. The high thermal mass of the trombe wall serves as a thermal storage medium, storing the absorbed solar radiation during the day and releasing it slowly during the cooler periods. Eighth are solar vents or dampers. To regulate the airflow between the wall and the interior space, adjustable vents or dampers may be included in the trombe wall design. This keeps things from getting too hot and enables temperature control.

Ninth is a passive operation. Trombe walls rely on natural phenomena like convection and radiation for their passive operation. They require little maintenance and consume less energy because they don't have any mechanical parts. Tenth is nighttime radiative heating. Radiative heating that occurs at night.

So, without the need for extra energy, the inside space is warmed by the heat that the trombe wall stores and radiates back at night. Eleventh is climate. Trombe wall works best in areas with large diurnal temperature differences where daytime highs are followed by colder nighttime lows. Let us now look at the advantages of a trombe wall. The benefits of a trombe wall are first, it's a passive solar heating system.

Without the use of active mechanical systems, trombe walls offer a passive solar heating option that uses solar radiation to heat interior spaces. Second is its energy efficiency. The trombe valve helps in lessening the dependency on traditional heating systems, which results in energy savings by collecting and storing solar energy during the day. Third is its low operating cost. Because trombe walls rely on natural processes like radiation and convection, they have minimal operating and maintenance costs after they are built.

Fourth are the benefits of thermal mass. The wall's large thermal mass facilitates efficient heat storage and progressive release, resulting in a more comfortable and steadier interior temperature. Fifth is its adaptability. Trombe walls can be modified for both new construction and retrofits in a variety of architecture and retrofits in existing buildings. Sixth is its environmental friendliness.

As a passive solar solution, trombe walls are environmentally friendly, reducing the carbon footprint associated with conventional heating systems. Let us also look at the limitations of the trombe valve. First is its slow response time. When it comes to heating and cooling, trombe valves respond slowly. The system might not react fast to changes in the weather, and it might take some time for the stored heat to be released into the interior.

Second is the risk of overheating. In certain areas or certain regions, there is a chance of overheating on sunny days, particularly if the wall is improperly insulated and there is no efficient way to regulate the air flow. Third is reduced efficiency. For better results, trombe walls need to be exposed to direct sunshine. When it is cloudy or overcast, they are less effective.

Fourth is the area needed. Trombe walls must be installed in a certain area, and sometimes it can be difficult to integrate them into already existing structures. Fifth is climate dependency. Climates - A wide range of daily temperature and lots of sunshine are ideal for trombe walls. They might not work as well in areas that are constantly overcast or hot.

Sixth is the design complexity. Proper consideration of elements including orientation, ventilation, and insulation is necessary while designing trombe walls. Ineffective design can result in problems with overheating. Seventh are the aesthetic considerations. Trombe wall design may not be for everyone's taste, and integrating them into particular architectural motifs may be difficult.

Eighth is moisture control. Condensation on trombe wall glazing may happen in humid locations, raising possible moisture-related problems. We next move on to see the properties and requirements. The first property or requirement is the orientation and shading. As we already saw, the position of the trombe wall south-facing in the northern hemisphere and north-facing in the southern hemisphere for maximum solar gain is important. However, we must avoid excessive east or west sun exposure, as this can lead to overheating in the summer.

And second is shading. Use overhangs, awnings, or deciduous trees to shade the trombe wall during the summer months to prevent overheating. Second is glazing. In underglazing, the first is material. Choosing a glazing material with high solar transmittance, that is, the ability to let in sunlight, and low thermal emissivity, that is, the ability to radiate heat, becomes an important criterion. Double-paint glass with a low-emissivity coating is a good option.

In terms of ventilation, incorporate vents at the top and bottom of the glazing to allow for natural air circulation and prevent its condensation. Third is absorber material. The absorber wall should be made of a material with high thermal mass so it has the ability to store energy. and heat, such as concrete, brick, and stone. The thickness of the absorber wall is also important and should be at least 6 inches thick to effectively store heat.

Fourth is the air channel. The depth of the air channel should be about 4 inches to 6 inches, or 10 centimeters to 15 centimeters, to allow for adequate circulation. The openings must be provided at the bottom and top of the air channel to allow for the natural convection of air. Fifth is control and integration. of vents and dampers. So, install vents and dampers in the air channel to control the flow of air and prevent overheating in the summer.

Meanwhile, integration with the HVAC system is important. So, consider integrating the trombe wall with your existing HVAC system for additional heating and cooling control. We will now see case studies. First is the single solar house. Let us now look at the case study of a single solar house.

The single solar house is the first solar heating device by Felix Trombe. in whose name this system has been named. And this was patented in France in 1956. Later patents included Anwar Trombé and were in around 1972. The Trombé wall house is in France, designed by architect Jacques-Louis Michel.

These were buildings that comprise the first Trombé wall detached house built in 1967. With relation to general functioning, this house had a wall with high thermal mass, which is the surface to be heated, and it sits behind an external glass panel. It operates as the mass, and it serves to transmit the heat to the interior space of the building. In the northern hemisphere, the external glass panels and the trombe wall must be placed on the southern facade as done here. The south wall absorbs the shortwave solar radiation that penetrates the glass.

The thermal mass is heated up and emits radiation of a longer wavelength. This radiation does not penetrate the first sheet of the glass encountered. The thermal mass absorbs the radiation and produces heat towards the inside of the building. Heat can be stored overnight in the thermal mass without mechanical assistance. The trombe wall is not restricted to latitudes where direct sunlight is abundant because the greenhouse principle also operates, for example, on cloudy days with diffuse solar radiation.

Here, the trombe wall includes two gaps on its top and base for air circulation, and during the winter, the air is heated behind the glass panel and it recirculates inside the building. During the summer, an inlet on the north-facing facade allows fresh air to enter for cross ventilation towards an aperture on the south-facing facade. The gaps at the bottom and top of the collector areas here connect the cooler air masses inside the building with the heated air masses in the collector. Due to the natural stack effect, cooler air flows in and at the bottom while the heated air flows out at the top. The thermal circulation of air is established throughout the building.

This detached house demonstrates that the thermal capacity of the collector wall is sufficient to reradiate heat for most of the night. In effect, a 35 cm thick concrete wall stores about half the heat absorbed by it. This is sufficient to maintain until the early hours in the morning. A warm air current is also generated. So, this is the principle on which the single solar house was built initially, and then its further variants, in a very small manner, were also carried out.

So, the first house prototype detached house had only a small gap glazing and vents and walls with high thermal mass, whereas the house built in 1917 France had installed another trombe wall system and this wall design had the openings or windows which were splayed but then it followed the same principle of having a glazed wall on which solar radiation strikes and an air gap creating an air current. So, today in today's class we saw a very simple technique, but a very effective technique to heat in cold climates, and this technique, this trombe wall, has been further taken by many people to have a number of variants. The concept is the same, but it has variations over a period of time. We will be seeing those one by one. For now, today we have studied about the trombe wall, which comprises an element to allow sunlight or heat inside, which is primarily glass.

Then the heat is trapped, which is primarily a thin air space. adjacent to a wall that has a thermal mass so that the wall absorbs the heat from the air gap. There are openings on top and bottom of the room because in that gap where air gets heated, the warm air rises up and gets inside the room through the vent on top. Once air gets on top, the cooler air descends and escapes through the lower vent into the air gap, which is waiting to get heated.

This is the concept behind a trombe wall. And this is how trombe walls are built, and many other variants of trombe walls would also be based on this. Hello everyone. So, in the last class, we saw about a simple system to tap solar energy and how that can be used to heat up the air and that hot air can be used to flush inside the house and make the house warmer, which is valid for a cold climate. We will see a small variant of the same thing called thermal storage walls with water walls. So, the type of thermal storage wall we will see today is the water wall.

So, heat storage walls are passive heating systems that make most of the solar energy to reduce the building's energy demand and operational cost. They depend upon the high thermal capacity of the walls to provide heating or cooling within the building. These walls are thick and have high heat capacity. They can be done with a combination of different materials like glass, concrete, water, and phase change materials.

There are mainly three types of thermal storage walls. One is the trombe wall, one is the water wall, and the third is the trans wall. Today we will be discussing the water wall. So, the water wall also works on a concept wherein the solar energy strikes a surface and the surface, whatever that surface may be, gets heated up. In this case, that surface is a water container; the container could be in any form. The solar rays heat this water container; it gets heated up, and then it transfers the heat to the air gap or directly to the wall, as the case may be, which radiates the heat or which circulates the warm air inside the room.

So, this is the concept of the water wall. So, water thermal walls are a type of passive solar heating and cooling system that uses water instead of solid materials like concrete or masonry to store thermal energy. Tubes or tanks are filled with water and are embedded within the water. Water has a higher specific heat than concrete, and this is the principle that is used. If we look at the evolution of water thermal walls. Way back in 1947, water-filled gallon sets were placed behind double-pane glass.

So, behind double-pane glass, there would be water-filled containers. Then slowly there was culvert storage. In 1974, fiberglass-reinforced polyester drums, which are semi-translucent, were placed. Then in 1980, translucent cylinders were used for water storage. Around 1980s to 1990s, a heat wall water wall system of vinyl bags in an aluminum and stainless-steel frame.

So, there were frames inside which vinyl bags with water were placed. In the 1980s and 1990s, rectangular steel tanks with low water walls were used. Also, thin steel wall tubes with plastic liners were used. In 2005, a suntainer and a sun bin, which are low-cost water wall modules, were used.

And then in 2018, a glass-based water wall was used. Like the pottery water wall, which was used in the hot, dry climate, the glass or glazing is set at a short distance from the water wall. Because the wall faces south throughout the day, it collects the solar heat and transfers the heat be absorbed in the water wall vents and windows, allowing the air from outside to be pulled over the water-saturated pottery pipes and into the building Let us look at the principle behind the water wall The principle behind the water thermal wall is based on the specific heat capacity of water, which is its ability to absorb or release large amounts of heat without experiencing significant changes in its composition or in its state. During hot weather, the water in the pipes absorbs heat from the sun and the surrounding environment. This heat is stored within the water and prevents it from transferring to the interior of the building, keeping it cool. Conversely, during cold weather, the stored heat in the water is released slowly, providing warmth to the building.

So, the concept of a water wall is that there is a glass cover that throws heat inside, and there is a structure that has water storage during the day. This heats up the water, which gets heated up during the day, and then this provides a good heat source to the space adjacent to it. During the hot weather, the water from the pipes absorbs the heat from the sun and stores it. When there is thermal insulation, this heat is not transferred to the room, and therefore this room remains cool during the summer. During winter, this insulation can be removed, and the heat from the water wall radiates itself into the room inside.

So, the heat transfer mechanism happens by absorption. During the day, the dark plastic pipes, pouches, or containers containing the water absorb the solar radiation, directly heating the water within. By convection, depending on the system design, the natural convection may occur within the tubes, circulating the warmer water towards the top and cooler water towards the bottom, enhancing heat transfer. Heat storage and release happen because of the high specific heat capacity of water, meaning its capacity to absorb a large amount of heat without experiencing significant temperature changes. This stored heat acts as a thermal buffer, mitigating temperature fluctuations inside the building.

Some systems also utilize phase change materials within the water pouches. These materials absorb and release heat when they change between solid and liquid states, enhancing the thermal storage capacity and providing more uniform temperature regulation. The phase change material should ideally melt during the day, absorbing heat, and solidify at night, releasing the stored heat and completing one cycle of thermal energy storage. Now the heat transfer to the indoor environment happens also with conduction. During the night or in cold weather, the stored heat in the water conducts through the wall materials, radiating warmth into the interior spaces.

Natural convection is also used depending on the system design. So, within the wall cavity, there can be a facilitation of movement of warm air towards the interior, further enhancing heat. Some additional factors that must be considered are insulation. Effective insulation surrounding the water pipes minimizes heat loss to the outside environment, maximizing its retention for indoor temperature regulation. Second is ventilation. Controlled ventilation can be integrated to remove excess heat during periods of high solar gain or to introduce cooler air during the night.

Control systems may include systems that regulate water flow, pump operation, and ventilation to optimize their performance for different weather conditions and occupant needs. Let us now look at a case study. Here we will look at the case study of Bear House. The Bear House is one of the most innovative experiments in the use of passive solar energy to heat and cool a modern dwelling.

It was built in 1972. And it is based on the inventor and designer Steve Baer. Located in New Mexico, the summers are extremely hot and dry. Whereas the winters are very cold and snowy. And it is mostly clear year-round. Over the course of the year, the temperature typically varies from 3 degrees Celsius to 33 degrees Celsius.

It rarely goes sub-zero or above 37 degrees centigrade. This house is made up of 11 zooms, which is a complex geometric shape resembling the cell of a honeycomb. This hovers above freestanding adobe walls and defys conventional expectations of what a house or even a solar house would look like. Bear cut into the hillside site to provide wind protection and privacy while allowing maximum sun exposure. He first erected a cluster of zones made from urethane-insulated aluminum panels. Applying zone geometries to a plan based on the hexagon, he erected freestanding, double-thick adobe walls beneath the zones.

To collect solar energy, Baer employed a system of south-facing walls stacked with 55-gallon drums of water called drum walls. These were painted black on the outward side of the facade. The water drums absorb heat from the sun, which is then radiated throughout the house. About 400 square feet of solar collection space are needed to heat nearly 2000 square feet of living space. For passive cooling, Bayer installed large insulated panels on the exterior, which are closed in the summer to block the drum walls from absorbing heat during the day.

At night, when the high desert temperature typically drops to between 62 and 65 degrees Fahrenheit, windows are lowered, overhead vents are opened, and skylights are opened to allow warm air to exit as cool air flows into the house. The house's adobe walls, ideal for their high thermal mass, help to retain heat in winter and keep the house cool in summer. This traps the cool air that flows into the house when windows, vents, and skylights are opened at night. The solar energy also supplies most of the hot water. A rooftop solar panel and a 12-volt solar-powered micropump heat and circulate water through the ground-level tank.

This is complemented by a passive thermosiphoning system that uses convection to operate without a pump. A ground-level outdoor solar collector panel is connected by hoses to an elevated indoor tank located in the attic, causing the hottest water to continually rise into the storage tank as cooler water flows back down to the solar panel. Since 1972, Bayer has resealed the aluminum panels in the roof structure to make them air and water tight while adding several inches of urethane foam insulation to improve heat retention. The passive thermosiphon system working depends on the collector that absorbs solar energy and transfers that thermal energy from the sun into the water.

The warming of the water decreases its density, causing it to rise through the system. The cooler substrate falls down the opposite side of the loop and into the collector. Let us now see the quantification of the effects on thermal comfort. So, this is based on a research paper by Singh and O'Brien, which is a semi-transparent water-based trombe wall for passive air and water heating. So, trombe walls provide a passive source of heating and ventilation for buildings.

However, the trombe walls can also cause overheating during hot and sunny weather conditions. In this work, the investigation of the potential of a multifunctional trombe wall design comprising a tinted acrylic sheet submerged in a water wall that functions as a thermal storage medium is conducted. The tinted acrylic sheet absorbs incident light, which is then converted to heat and absorbed by the water. Furthermore, heated water rises to the top of the trombe wall where it can be removed, which provides the dual benefit of preventing overheating and providing a source of preheated water for application within the building. The experimental results performed on the laboratory scale trombe wall prototype showed that the percentage of solar simulated light energy incident onto a trombe wall prototype over a period of 5 hours that was stored as thermal energy in the water increased from 60.

3% to 83.2%. when tinted glass was inserted in the water storage wall. Furthermore, the temperature of the water at the top of the trombe wall reached 55 degrees Celsius, which is suitable to be used as preheated water in any building application. It has been reported that the trombe wall can reduce a building's heating demand by 30%. Another study showed that the thermal performance of a trombe wall consisting of a wall as a thermal energy storage medium was improved. The results showed a reduction in energy consumption per year by 8.6%, and the indoor thermal comfort evaluation index was improved by approximately 13% as compared to a regular classic trombe wall.

One of the ways to reduce overheating from trombe walls during summer is to use water as the thermal storage medium. Water has a high heat capacity and can store more thermal storage than other thermal storage walls on a per-volume basis. The high heat capacity also keeps the temperature of the wall, the trombe wall, lower than the other trombe walls. This can help reduce thermal losses to the surroundings. When we look at the prototypes, this was constructed to experimentally investigate and compare the ability to store solar thermal energy in water storage walls with and without tinted glass.

The trombe wall prototype was built using 3.8 by 3.8 centimeter wooden frames because of their low thermal conductivity.

The overall dimensions of the model frame were 58.4 x 38.1 x 66 cm. The frame was insulated using 1.5-inch-thick extruded polystyrene insulation boards, which have a thermal conductivity of 0.029 watts per square meter. The front view of the trombe wall prototype when water tank with acrylic tinted plexiglass is as shown in this figure. When we look at the quantification of effects on thermal comfort, it can be noted that there was flexibility in how the heated water at the top of the water storage medium could be used. The heated water could be removed from the storage medium as soon as it was no longer being heated when the light was turned off in this experiment, or it could be stored and used to heat water or air at a later time.

In this scenario, the water-based trombe wall can act as a storage medium until the hot water is needed a few hours after sunset. In practice, hot water could be used to supply hot air to the building for hours after sunset by opening the trombe wall vents. So, four cases were studied. In the first case, there was water stored outside. And the thermal storage valve was made up of water in a plexiglass container, and on the rear side was a single plexiglass sheet.

Whereas in case 2, it's the same thing, but on the front side there was a tinted plexiglass sheet attached. In the third case, there was a thermal storage wall in a plexiglass container, and on the rear side had two plexiglass sheets separated by 2.5 centimetres. The fourth case showed the thermal storage wall with water in the container and the rear side of the trombe wall had two plexiglass sheets separated by two and a half centimeters, and the front side had a tinted plexiglass sheet inserted in on its front and you can clearly see what happens to the temperature each of these surfaces, so throughout the trombe wall prototype you can see which case is better than the other, so the best performing of all is case 2 and case 4, so there is a definite impact of having a glass in front of the container that has water.

So the highest thermal efficiency estimate in this work was 83.2% for case 4, when the trombe wall prototype had tinted glass in the thermal storage medium and two plexiglass sheets at its rear side. It was expected that the thermal efficiency of the trombe wall could be increased by using a tinted acrylic sheet with a higher absorptance. However, increased absorptance would also reduce the amount of light entering the room.

So, a via media must be created. So, case 4 was best, and after that, case 2 followed through. So, the conclusion showed that the experiments were performed so as to evaluate whether the proposed trombe wall design could provide heated water during hot weather operating conditions when the vents at the top and bottom of the trombe wall are closed. The best results were obtained when the tinted acrylic sheet was placed in the storage wall medium and when two clear plexiglass sheets were used at the rear side of the prototype to increase insulation. Under these conditions, the thermal storage efficiency of the trombe wall was 83.2%, and the water at the top of the storage medium reached a temperature of about 56 degrees centigrade.

After being subject to illumination from solar simulated light with a good intensity of 44.4 MW per cm2 for 5 hours. So from this experimental study, it showed that instead of having a stand-alone water wall, it is better to have a layer of glass in front of the water wall in order to increase the efficiency of the system. So, in today's class, we saw an advanced passive technique called water wall, which is based on the trombe wall concept. In the next class, we will study yet another concept of advanced passive architecture.