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: 11

Lecture 03

Passive Design Strategies for cold climate and case studies
Hello everyone. So, last class we saw part one of moderate climate, where we saw the strategies that should be adopted in the moderate climate, and after that, we saw the application of these strategies with respect to case studies. Today, we will have a look at the cold climate. So in a cold climate, what are the strategies that should be adopted?

Simple passive strategies and advanced passive strategies, as well as we will have a look at one case study. So, first, we will look at how Mahoney's has conceptualized these simple passive strategies for a cold climate like Shimla. If you look at Shimla, in the previous class, I had told you how to use Mahoney's table. In a similar manner, I have used Mahoney's table, and this suggests the criteria or climate strategies that must be adopted. So, for Shimla, Mahoney's suggests that the orientation should be north and south.

- With the long axis along east and west.
- The building must have a compact layout.
- The rooms must be single-banked with permanent provision for air movement, though actually, air movement is not required.
- Openings should be medium in size.
- Heavy external and internal walls must be used.
- And the roof must be light and insulated.

So now let us see how the psychrometric chart of Climate Consultant is going to help us in identifying the correct simple passive, advanced passive strategies, and whether we require any active means to ensure that all 100% of the hours in the building are comfortable. Now let us see for the March solstice. What happens during the month of March? So during the month of March, in a cold place like Shillong having a cold climate-representative of a cold climate, for the month of March,

What happens? What strategies must be adopted? Now, comfort naturally occurs for 23 hours or 3%. Then adaptive comfort ventilation can make the uncomfortable hours comfortable by 5.6% or 42 hours. Internal heat gain methods can make the indoors comfortable for 307 hours or 41.3% of the hours.

Then passive solar direct gain low mass can cause 20.8% to be comfortable for the month of March alone. And passive solar direct gain high mass can cause 6.3% of the hours to become comfortable. Therefore, by following only passive strategies, we can get 52% of the hours to be comfortable for the month of March. Yet we have some areas which are uncomfortable.

So this part of the month can become comfortable by having passive solar direct gain. With the help of low mass. Whereas these hours can become comfortable if we use passive solar direct gain with high mass. So this is how you should identify on the psychrometric chart. You see,

These hours, I will just change the color. These hours are still not shifting from discomfort to comfort without the use of active means. So, in order to shift the remaining hours, that is, the hours here also from red, you can see it has become Green, comfortable. What are the strategies that must be followed?

See, these are all passive strategies. So far, we saw passive strategies, till here in the previous slide. Then the active strategies would be to have dehumidification. And to have heating and humidification in order to make 100% of the hours comfortable by making these 49% comfortable by the use of active means. For the month of March, for a cold climate like Shillong.

This is the strategy to shift the remaining percentage of 49 to comfortable from extremely cold or uncomfortable areas. So, what are the design guidelines to shift these from uncomfortable to comfortable? So, heat gain from lights, people, and equipment will greatly reduce the heating need. So, keep the home tight and well insulated so that it can lower the balance point temperature.

Sunny, wind-protected outdoor spaces can extend living areas in cool weather by having seasonal sunrooms, enclosed patios, courtyards, or verandas. Then, trees, neither coniferous nor deciduous, should be planted in front of passive solar windows because they will cast a shadow on the window. But it is okay beyond 45 degrees from each corner so that this wall is free of any shadow from these trees.

Then, tiles, slate, or even wooden floors or stone-faced fireplaces can provide enough surface mass to store winter daytime solar gain and nighttime cooling or flushing. We can organize the floor plan so that the winter sun penetrates the room during daytime use, and with specific functions, this can coincide with the appropriate orientation of the room. Then, small, well-insulated skylights. which are less than 3% of the floor area in clear climates and 5% in overcast, can reduce daytime lighting energy and cooling loads. Let us see what is needed for the month of June.

For the month of June, what will make this place with just simple passive and advanced passive strategies. So, passive strategies for the month of June for Shillong, which is representative of a cold climate. We can see that automatically 4.3% of the time is comfortable. By using sun shading of windows, 3.5% of the hours or 25 hours become comfortable.

Then, adaptive comfort ventilation can push 84 hours or 11.7% of the time into comfortable mode. Then, internal heat gain can shift the comfortable hours from uncomfortable to comfortable hours. 65.1% of the hours or 469 hours can become comfortable. Then, 48 hours or 6.7% of the hours can become comfortable by using passive solar direct gain with low mass. Then, passive solar direct gain high mass can shift from uncomfortable to comfortable for 3.1% or 22 hours of the month. So, effectively, if you see 81% of the time, 81% of the total hours are comfortable in the month of June with passive strategies alone. There is still 19% of the hours which are not comfortable and that requires active means.

Out of 720 hours, how do we get the 720 hours? Say for the month of, June. So, 30 days into 24 hours. 720 hours.

Out of that, 582 hours are comfortable just with appropriate passive strategies. Now do not use more passive strategies because that is only a waste of money and time. So exactly what strategy to use and how that will cause a shift, the psychrometric chart will help you to ascertain. Then in order to make the remaining months also 100% comfortable, what strategies must be used? So for the month of June, just dehumidification will shift

219 hours out of 720 hours to comfortable mode, that is 30.4 percent of the time will become comfortable if you use dehumidification. Also, heating only for one hour is required in that entire month. So With just these two active strategies, or I will say primarily this active strategy, you can shift almost 100% of the hours into comfortable mode. So only one hour of the month lies in this zone, whereas all the other hours can be sorted with these strategies.

So, what are these strategies, and how do we use these design guidelines? So, first, this is one of the more comfortable climates. So, shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter. The next strategy is that traditional passive homes in cool, overcast climates used low-mass, tightly sealed, well-insulated construction to provide rapid heat buildup in the morning. For passive solar heating, most of the glass area in the south must be used to maximize winter sun exposure.

But we must have design overhangs to fully shade in summer. So, provide double-pane, high-performance glazing on the north, west, and east, but clear on the south for maximum passive solar gain. We must try to facilitate cross-ventilation by providing openings on appropriate walls. But not along the wall which will bring in the cool air. Low-pitched roofs with wide overhangs work well in this climate for some months.

Let us see what is required in September. For the month of September, 8.5% of the hours are comfortable by itself, which is 61 hours. Three hours out of 720 can become comfortable by sun shading of windows. So, in September, it shows that you do not require shading the windows too much because, by doing so, only three hours can become comfortable.

September in Shillong is representative of Cold climate. 9.4 percent of the time, or 68 hours, requires adaptive comfort ventilation, whereas internal heat gain can shift to comfort hours by 500 hours out of 720. 500 hours can become comfortable if you have good internal heat gain, which accounts for approximately 70% of the month. Then, using passive solar direct gain low mass will shift 43 hours from uncomfortable to comfortable hours. Whereas, passive direct gain high mass will shift 3.3% or 24 hours from uncomfortable to comfortable. So, these are the passive strategies accounting for 86% of the time to become comfortable. Yet, we still have 14% of the time which is not comfortable and for which we may require some kind of active means. So, what are those active means?

So, those active means are dehumidification for 158 hours. So, 21.9% of the hours can become comfortable if we are able to use dehumidification. Whereas, 0.3% of the hours can become comfortable if we add heating. So, totally 100% can become comfortable out of 720 hours if we are able to provide dehumidification and if we are able to provide heating here.

So, by adapting these two strategies, which are passive and active, accounting for say 22% and 78% of the month of September, we can make the indoors comfortable. So, how do we adapt these strategies? So, one is we can use raised floors

Well insulated -because a heavy slab is of little benefit for thermal storage in a cold climate or small day-to-night temperature difference. If the soil is moist, then we can raise the building on pilings and minimize dampness and maximize natural ventilation. Heat gain from lights, people, and equipment greatly reduces heating needs. So, we should keep the home very tight and not allow any heat to escape. And therefore, it should be tight and well insulated.

Then, what all can we do in a wet climate? Well-ventilated attics with pitched roofs work well to shed rain and can extend to protect entries, porches, verandas, and outdoor work areas. We can also use stack ventilation even when wind speeds are low and maximize vertical height between air inlet and outlet with the help of open stairwells, two storage spaces, roof, etc. Now, what strategies should be used in December? In December, for a cold climate, like Shillong, none of the hours are comfortable by themselves.

Adaptive comfort ventilation is not going to be helpful. Internal heat gain can help for 159 hours or 21.4 hours to shift from uncomfortable to comfortable time. Also, passive solar direct gain with low mass is effective for 16% of the hours, and passive solar direct gain with high mass is effective for only 0.16% of the hours. So, in total, only about 29% of the hours are comfortable with passive strategies. For the rest of the hours, there is definitely a need for active strategies because we can even understand how cold Shillong will be in the month of December.

So, what is the strategy that should be used? It is primarily heating. So, heating is the primary strategy. To shift the remaining 71.2% from uncomfortable to comfortable. So, out of 744 hours, 530 hours definitely require heating.

So, these are the passive strategies, and this is the active strategy. So, passive strategies will account for only 29% of comfortable hours, whereas 71% of the comfortable hours will come only with the help of active means for Shillong in the month of December, which is a cold climate. One way to do it, and that is primarily to heat. So, if a basement is used, it must be at least 18 inches below the frost line and insulated on the exterior with foam insulation or on the interior with fiberglass insulated walls so that we are able to insulate the building from the cold as well as benefit from the earth's warmth during that time. Insulating blinds, heavy draperies, or operable window shutters will help to reduce winter nighttime heat losses.

Windows can be unshaded and face in any direction because any passive solar gain is a benefit, and there is little danger of overheating. So you can allow as much heat to come in as possible because there is no risk of overheating during this period. Extra insulation, known as super insulation, can be effective and will increase occupant comfort by keeping indoor temperatures more uniform. A high-efficiency furnace with an Energy Star rating can be effective in making the interiors warm. We can locate garages or storage areas on the side of the building facing the coldest wind so that it will help to insulate the other occupied or inhabited areas if the cold draft does not fall into these occupied areas.

So these are the strategies that can be used in the month of December. Now let us compare and see what happens in all these four periods. So comparative analysis for Shillong, which we represent as a cold climate, What are the passive strategies and active strategies for us to have a sustainable building?

So for the month of March, with just the passive strategy, only 52% of the time period can become comfortable. Whereas in June, with passive strategies alone, 81% of the hours are comfortable, and in September, 86% are comfortable with just passive strategies. But in December, only 29% of the hours can be made comfortable with passive strategies. Internal heat gain, nearly 41.3%, can be made comfortable with internal heat gain. In June, it is 65.1%, and 69.4% of the month of September can become comfortable with just internal heat gain, whereas for December, only 21.4% is effective in making the indoors warm with internal heat gain.

It means that internal heat gain is most effective for the month of June. Then passive direct solar gain with low mass is needed throughout the year, but it is most effective for the month of March only, as compared to the other months. So passive solar heat gain with low mass only has an effect of 6.7% for the month of June. Whereas in September, it is only 6%.

And in December, 16% of the hours of the month can shift from discomfort to comfort with passive solar direct gain with low mass. Passive solar direct gain with high mass is again most effective for the month of March, with 6.3% of the hours being shifted from uncomfortable to comfortable with passive solar direct gain high mass. Whereas these numbers are very small for the month of June, which is 3.1%. 3.3% and 1.6% show that passive solar direct gain with high mass is not a great way to make the indoors comfortable when it is uncomfortable during the months of June, September, and December. Adaptive comfort ventilation is not to be used in the month of December but can be used for the other months and is most effective with 11.7% of the total uncomfortable hours shifting from uncomfortable to comfortable, which is in the month of June.

Sun shading is not a great way in this place at all because we can clearly see that you should not use solar shading. from December to say May or June, and sun shading is effective in June and September, but in June it is only for 3.5 percent of the time and 0.4 percent in September, which is almost so I'll put a dashed line which is almost not an effective or worthwhile strategy. Active strategy. So what are the active strategies?

Active strategy is heating and humidification. So heating and humidification is most effective for the month of December, with 71% of the time shifting from discomfort to comfort, and for 48% in the month of March. Whereas for June, 30.4% of the hours are effective with dehumidification as the strategy, and for September, 22% of the month becomes comfortable by dehumidification. With dehumidification, for the month of March, 1.2% of the time shifts from uncomfortable to comfortable. So

suppose you have this kind of comparison for all 12 months, then you will be able to assess and pick which is the best strategy for that place, which will make the place comfortable for most periods of the year, and how you can optimize the strategy. And in this way, you should use the psychrometric chart to assess the passive strategies and active strategies of a cold place. Now we will see the other aspects of how to design in a cold climate. Now let us look at the passive strategies for a cold climate.

In a cold climate, the building orientation, the first criteria we will see is building orientation. So optimum sun absorption is crucial for thermal comfort in cold climates.

Orientation must be in a way that takes full advantage of the sun during both summer and winter. A building which is elongated along the east-west axis leads to additional absorption of sunlight on the south side during the winter season.

The second criterion is building form. So, in cold climates, Indoor air is cooled in the process of it flowing from inside to outside. This could lead to excessive water vapor condensation if not considered during the design. So, you need airtight construction, which will prevent hot air from escaping from the building envelope and cold air from entering it.

Second, have covered entrances and open spaces, as they can prevent excessive cold air from disrupting the comfort of the user while entering or exiting the building. Third, have recessed entryways, which help protect the entrance from prevailing winds. Then, the third element is Then, the third aspect you should consider as a simple passive strategy is to use open spaces, which need to be protected from prevailing cold winds. Interior spaces inside the building need to be zoned based on the needs of each space with regard to solar and ventilation requirements.

The fourth consideration should be daylighting. Make the most out of the available natural light on the site and design openings to let in maximum light. Use glass facades and roofs for appropriate daylighting for spaces that require the most light. Then, the fifth aspect is ventilation: cross ventilation. Placing windows at multiple facades in the right places can assist the exchange of existing air with new air in the summertime.

But this is not valid, applicable, or to be encouraged during the cool season or the cold season, as you will end up bringing in cold drafts. Stack ventilation can be encouraged since the prevailing wind tends to be at a higher pace in cold climate areas. This wind can be used in stack ventilation and also for energy production in the form of chimney effect, wind towers, ventilators, evaporative cooling, and so on, but only during the summer time and not during the winter time. Air locks or lobbies for insulation can be used. Sealing the doors and openings with air locks will help equalize air pressure between inside and outside.

Use high-performance windows as they perform at least 15% better than normal windows. They are made using insulating frames, which can provide light and sound control and also cut off the chill from outside. Next is shading. So, cold climates often need highly glazed facades for maximum natural lighting. Right shading systems need to be designed to reduce the cooling demands of a building.

Installing automatically controlled shading systems will help users choose the correct need for shade at the right time. This can be by means of overhangs, awnings, louvers, and sometimes even vegetation. The roof must be protected from direct solar radiation. Next, we will see openings. Double glazing on windows is highly effective for cold climates to efficiently reduce heat loss.

Provide south-facing glass windows to maximize heat gain during the winter months when it is coldest. Window glazing with a low U-factor will help reduce winter heat loss and retain heat from the day for use during the night. The glazing should be well-insulated to prevent the leakage of heat to the exterior. 8. Providing shared walls helps reduce heat loss by decreasing the number of walls exposed to the exterior environment.

Facades with high thermal mass are a good option when there are large temperature variations. Thicker walls will help insulate the space and retain heat inside the building. Darker-colored exterior walls are preferred to help absorb the maximum amount of heat. Ninth is roofs. In spaces where there is a lot of rain or snow,

The provision of steep and sloped roofs will help prevent water stagnation on the roof. So, provide materials and designs that allow maximum solar penetration into the building, such as glass. Tenth is building materials. Insulating materials such as timber and mud plaster can be used on the walls to create facades that prevent heat loss as much as possible. Timber-paneled walls and windows will help reduce the rate of heat transfer and are also mostly available in cold climatic spaces.

Next is landscaping and vegetation. Use trees as natural wind barriers or buffers by planting them near windows to block cold air from entering the building. Plants and trees chosen for landscaping must be able to survive the harsh climatic differences. Let us look at the appropriate passive design strategies for cold climates by looking now at the advanced passive strategies.

First is direct solar gain. Now, in the direct gain method, the building is designed to be directly heated by solar thermal energy, and the living space acts as a collector of This direct solar energy which can penetrate into the room. So the wall and the floor act like storage for the solar energy. And so heat gets stored.

So if you use direct gain solar glazing, the solar glazing will admit the heat directly into a space for passive heating in winter. So solar glazing, like facing the equator, is sized to admit enough sunlight on an average sunny winter day to heat a space over the full 24-hour period. The variations of these must be used, like the trombe wall, sunspace, water wall, thermosiphons, etc. Then we look at the next strategy, which is the thermal mass. So thermal mass refers to the ability of the material to absorb, store, and release this heat energy.

Materials with high thermal mass can absorb and retain heat for an extended period, helping to regulate temperature fluctuations in the space. The third strategy is earth sheltering. The thermal mass of the earth provides a natural insulation barrier. Earth has a high thermal inertia. This means it can absorb and store heat during the day and release it at night, helping to maintain more stable temperatures within the sheltered space.

The earth acts as a barrier, reducing the exposure of the building to cold outdoor temperatures. This helps to minimize heat loss, providing energy savings and improving overall energy efficiency. It is also a windbreak. Now, you can also use indirect solar gain. The indirect gain method requires a buffer thermal mass between the sun and the living space to be heated.

The thermal mass buffer can be a structure, a wall system, an absorption device, and/or another space. Unlike the direct gain method, the indirect gain system has the thermal mass act as a collector, absorber, and distributor of the solar energy. Thermal distribution is accomplished through conduction, averaging 40% utilization rates. Among these, the first is the trombe wall.

Now, a trombe wall is a massive equator-facing wall that is painted in a dark color in order to absorb thermal energy from incident sunlight and covered with glass on the outside, with an insulating air gap between the wall and the glaze. The second one is the solarium. The use of a sunroom as a hybrid method includes the functions and benefits of both the direct and indirect gain methods. It is an enclosed space surrounded by multiple or large apertures like windows for maximum sunlight entry. Then, it is transferred to the living area through conduction from a shared wall or through wall vents.

In the vent system, the amount of heat transferred may be controlled by opening and closing the vents. Then, for reducing heat losses, the systems that can be used are first, cavity walls. A cavity wall is a structure that protects from outdoor cold by creating a thermal barrier. The air gap within the wall cavity acts as insulation, limiting the direct transfer of cold temperature to the inner layer of the wall.

Also, the insulative property reduces heat loss as the inner wall doesn't get as cold as the outdoors. Second is insulation. In order to reduce heat loss, insulation limits the direct transfer of cold temperature to the inner layer of the wall. Also, the insulative property reduces heat loss as the inner wall doesn't get as cold as the outdoors. The third strategy to reduce heat loss is double glazing.

The air or gas-filled gap between two panes acts as a thermal insulator. Air is a poor conductor of heat, and the gap reduces the direct transfer of heat from the inside to the outside. Low-E coating Many double-glazed windows are coated with low-emissivity coating. This thin, virtually invisible coating reflects radiant heat, helping to keep warmth inside the building during colder times.

Then we will look at Heating systems: advanced passive heating systems to be used in cold climates. First is the radiant heating system. A radiant heating system is a method of heating indoor spaces by transferring heat directly to the surfaces and occupants within a room. Radiant heating warms up surfaces, which then radiate heat to the surrounding environment, embedding pipes in walls, floors, and roofs that have liquid or water that transfers the heat to the elements, which is then radiated to the room.

The second heating strategy is thermosiphon. A thermosiphon solar air heater is an alternative energy source that uses the sun's rays to pump air into a house and stores heat in a bed of rocks. The collector glazing heats the screen absorber, which heats the air around the absorber. This becomes more buoyant and rises out the top collector vent, pulling new cool air into the lower collecting vent.

The third strategy we will see is geothermal heating. Geothermal HVAC systems take advantage of the relatively constant temperature of the earth beneath the surface. It can have a closed-loop system. In a closed-loop system, the network of pipes containing a heat transfer fluid, often a mixture of water and antifreeze, is buried underground. The fluid circulates through the loop, transferring heat to or from the ground, and then enters the building to provide a space heating system.

So today, we will have a look at the Bullitt Center in Seattle, which has an area of 4380 square meters, and we will look at the passive design strategies adopted in this building. Now, the Bullitt Center in Seattle, Washington, is a commercial office building that achieved net-zero energy, water, and waste certifications. This building is a private one and is an office. The challenge of this building is that it uses geothermal wells, solar panel arrays, and rainwater collection to be fully self-sufficient. This building, the Bullitt Center, is a commercial office building.

It was officially opened on Earth Day, April 22nd, 2013. It was planned to be designed as the greenest commercial building in the world. This building is certified as a Living Building by the International Living Future Institute. This building was built by a non-profit group based in Seattle. This building has been designed with a 250-year lifespan.

This building produced nearly 30% more energy than it needed for all its uses, with the help of solar panels on the roof. As a result, it is one of the largest net-positive energy buildings in the world. Now, as a design process, integrated design involves multidisciplinary collaboration from conception to completion and delivery of the building. Integrated design strategies are a combination of architectural, mechanical, electrical, and structural elements working in a combined manner to achieve a high-performance building. The design strategies employed in this building are relatively common in modern buildings, and the technology that is used is also readily available.

But so far, not all buildings have used all the strategies to have a fully integrated state-of-the-art technology and high-performing design strategy employed in the Bullitt Center. And none are as large or as ambitious in their performance goals. The plan of the building is relatively simple, with a large open floor plan, service core, and staircases. The high-performance design is about designing with nature. It begins by asking a primary question.

Which is, what will nature allow us to do on this site? This means considering the conditions for all 8,760 hours of the year and having an understanding of how day and night temperature swings happen, the rainfall pattern, the cloud cover, and the hourly availability of the sun, wind, and light. After that, one must make informed decisions about how to approach the project. First, let us look at the strategies that were followed in this design. The first one is the building form.

Now, the building form of the bullet center is not driven by aesthetics alone or some narrative or metaphor. But it is based on the performance matrix. Each dimension of the building's design, its energy and water use, its durability, its longevity, the toxicity and origins of the materials, its function, form, and organization all had exceptionally high performance thresholds to meet. A variety of building forms were tested, each with different surface-to-volume ratios, as we had seen in the previous class, how surface-to-volume ratio matters and aspect ratio also matters. So,

A variety of building forms were tested with different surface-to-volume ratios but with the same proportion of window-to-wall area. So, larger surface-to-volume ratios increase winter heat loss. However, this loss could be offset by an increase in heat gain through the windows on a sunny winter day. Next is the building structure. While concrete was considered, timber was chosen for its lower embodied energy.

The hybrid structure combines concrete, steel, and timber. The emphasis was on natural finishes, the use of local materials, and minimal waste during construction. Resulting in a sustainable and visually appealing building. All the structural materials used in the bullet center were locally sourced and were within 300 miles for steel and concrete and 600 miles for wood. The base of the building used concrete,

A heavy timber structure above the third floor has been used. Steel connectors provide seismic and fire safety reinforcement. The high-performance envelope comprises a triple-glazing curtain wall system designed to minimize thermal bridging and air infiltration. The building's massing, orientation, and window selection control heat gain. Significant glazing faces south and north for improved daylighting.

Automated windows optimize heat and solar control while maintaining visibility. Operable shading systems are used for glare control, and to reduce solar heat gain. Operable windows allow for free cooling and ventilation under suitable ambient conditions. So, integrating a system of triple-pane glazing, automated exterior Venetian blinds, and operable windows helps to maintain the interior temperature, serving as a primary system of building temperature and CO2 control. So, having these windows and shades provides thermal control, air control, as well as daylight control. The next feature is solar panels. So, 575 solar panels have been used on the terrace of this building to generate more energy than the building uses in a year. One meter measures energy sold to the electric utility.

One measures energy purchased. So, 240,000 kWh per year is the expected total energy generation by on-site photovoltaic arrays alone. Here you can see how the solar energy that is generated is also calculated and diverted to appropriate work areas. So, lights are used for lighting purposes.

So many solar arrays are used. For heating and cooling purposes, so many solar arrays are used. For ceiling fans, so many solar arrays are used. For ventilation fans, so many solar arrays are used. Pumps utilize this many solar arrays.

Domestic hot water. So much energy is used for domestic hot water. Elevators utilize this much solar energy. The servers in the offices and commercial areas utilize so much. Laptops utilize so much solar energy.

Workstations utilize a significant amount of solar energy. The monitors in the office utilize this amount of solar energy. Computers and printers utilize this amount of solar energy. Appliances use this amount of solar energy. And toilets and other systems use this amount of solar energy.

And as a safety factor. There is some solar energy also available in excess. So this is the split-up proportion of solar energy used in this building. The third is radiant floor heating and cooling with passive cooling and natural ventilation. We have seen this system over and over again, and it is a very effective system.

So heating and cooling use ground source heat pumps and geothermal wells. Radiant heating and cooling systems maintain comfort. Ventilation relies on a 100% outside air unit with an air-to-air heat exchanger to precondition incoming fresh air with outgoing air, ensuring efficient air quality control. Now the spaces are heated with warm water, which is circulated in tubes and embedded in the concrete floor plates.

The warmth comes from the building's ground source heat exchange system, which is the geothermal energy that pumps water from underground at a depth of 400 feet. So, 26 geothermal wells take the mixture of glycol and water from 400 feet below the earth to reach a temperature of 53 degrees Fahrenheit, and that is pumped into the pipes on each floor, which radiate the heat and warmth into the building. So, the glycol mixture absorbs the ground's warmth before it is pumped back and run through heat pumps in the mechanical room that warms the 53-degree fluid into 90-degree Fahrenheit fluid.

Then, as a sustainable system, there is the use of greywater in this building. The reuse of greywater saves a lot of energy. The project reuses greywater and infiltrates it back into the ground. Water from sinks and showers is stored in the 550-gallon greywater tank, treated in a three-stage filtration process, and reused in the vacuum flush toilet system. The greywater system was updated when the composting toilet system was replaced with a vacuum flush system in 2021.

Greywater treatment and on-site disposal replicate the historic site hydrology through infiltration, evaporation, and pipe discharge. So, water is collected and reused, and water used in sinks, showers, and dishwashers throughout the building is drained into a greywater tank in the basement. This water is undergoes treatment, and after undergoing treatment, which involves a three-stage filtration process. This water, which is approximately 0.4 gallons of finished or treated greywater, is used for toilet flushes throughout the building.

Rainwater is harvested. So, 69% of annual rainwater runoff is collected, treated, and stored for potable and non-potable purposes. 100% of the water used in the bullet center comes from captured rainwater. Greywater is treated and reused in the vacuum flush toilet system, and excess greywater is returned to the soil to help recharge the aquifer. Toilets are composted.

So, vacuum toilets have been used. So, human waste management through the 10 basement composting units produces compost for soil amendment. A highly efficient vacuum system uses just 0.4 gallons of treated greywater per flush. After 7 years of operation, the composting toilet system was removed in 2021 and replaced with a vacuum flush system. The vacuum system uses 70% less water than a standard flush toilet.

The vacuum pumps pull waste through the grinder to eliminate problematic solids before moving them into a collection tank. From the collection tank, waste goes on to the sanitary sewer for treatment. Like in the composting system, solids from the sewage treatment plant are converted into a human biosolid called loop, which can be used as fertilizer. So, human excreta and toilet paper travel from toilets to the composters placed in the basement. Aerobic decomposition heats material up to 165 degrees to kill pathogens and control moisture.

And then what happens during that process is deposits from toilets are added to sawdust. And then the composting material sits, becomes mature compost, and turns into biosolid. The leachate is removed and used to restore local construction bed plants, and the biosolids are removed and made into Groco compost. So the solid material is composted into a nutrient-rich biosolid and made into Groco compost. Next, we look at the building neurology.

So computers automatically adjust passive and active systems to keep the building comfortable and efficient by means of a system. The building automation system controls include heating, cooling, passive ventilation, mechanical ventilation, daylighting, and other systems. At the Bullitt Center, the building management system is responsible for the control of the heating system, cooling system, active and passive ventilation systems, daylight control, composter, greywater metabolism, and security. All these systems are carefully monitored for maximum efficiency at the main control room in the core building. Then there are irresistible stairs to promote human health for the occupants of the building.

There are a number of staircases with views of downtown Seattle. So this also encourages people to use the stairs instead of the lift and promotes activity amongst the users of the place. So if you look in total, this building has a building life cycle which is designed for 200 years, with a structure of heavy timber, concrete, and steel. The skin has a 50-year performance and is a high-performance envelope. The technology is 25 years old.

The technology is designed for 25 years and features active solar control photovoltaics. When it comes to water, there is rainwater collection which meets 100% of the site's demand. Gray water is recycled, so 100% of gray water is treated. Waste is composted and converted into fertilizer. When it comes to energy, ground source heat exchange, radiant heating, cooling, and heat recovery air systems are used.

Natural ventilation is used for night flushing and operable windows. Energy is utilized where 100% renewable energy on the side grid is used as a battery to store energy and direct it to various areas where energy or electricity is required. So, if we look at the energy consumption of this building, the predicted energy usage was simulated. The actual energy usage of this building was mapped against the predicted energy usage.

The simulated energy or the predicted energy usage of this building showed that this red line represents the predicted energy usage. The building is predicted to use this much energy, whereas it actually used a much smaller quantity of energy, as you can see. There is this much gap between the predicted energy usage and the actual energy usage. So the building has used much less energy than it was predicted to use. Let us now look at the energy production, both actual and predicted.

So, you can see that the actual energy production of this building follows this line. Whereas, the predicted energy production, which I will mark in yellow, follows a similar trend. There is hardly any difference between the actual energy production and the predicted energy production. Now, if we look at the actual energy used by fuel, the end use, and the annual on-site renewable energy, you can see that this building has been able to generate its energy in surplus. And therefore, this is an example of a regenerative building or an energy building. So, you can see the actual energy consumption versus the predicted energy consumption and the difference. So, you can see there is a 41.7% difference between the actual and the predicted energy consumption, resulting in a difference of about 42%. Whereas, the actual energy produced and the predicted energy produced, the difference is minus 2.3%.

which means about 2.3% of energy is produced in excess of what was already predicted. So, this graph suggests how much energy should be used for which criteria. And you can see, as compared to the Energy Star Score or as compared to the Seattle Energy Code Building or LEED Platinum Building, the proposed building consumes energy which is less by 83% as compared to the Energy Star Score and as compared to the other systems. Also, it uses much less energy. So, again here we see that there is a gap between the actual and the

Predicted energy use creates a surplus of 41.7% energy. So, a typical building of this size will have an energy use intensity of 72, whereas a PV array with an area of 64,348 square feet is required to meet the energy use intensity of a typical building. A building of this size, in order to meet the Seattle Building Energy Code, requires 44,752 square feet of solar PV panels. A LEED platinum-certified building requires 28,599 square feet of solar PV in order to enable the functioning of this building, whereas the actual design required only 14,303 square feet of solar PV panels. That is because the consumption of energy in this building became much less by virtue of adopting the other Passive strategies. So, we look at the performance-based design. The goal of achieving a net-zero building resulted in a performance-based design approach. First, it set aggressive goals.

Net zero was the energy performance goal of the Bullitt Center. And energy and design analysis following the design charrette resulted in a six-story, 50,000-square-foot space for a photovoltaic power plant that could supply the annual energy needs of the building. And the second step was to analyze the site and climate. High-performance design is about designing with nature. This means considering conditions during the 8,760 hours of the year and understanding the day-to-night temperature swing, rainfall, cloud cover, and every single climate parameter.

The third step was designing for reduced energy demand. The building's form, envelope, and organization were informed by the climate, use, and the building systems rigorously tested, modeled, and evaluated to optimize its performance. The objectives are a comfortable, healthy, beautiful building that can function without the need for mechanical assistance as long and as often as possible. The other half is to make it easy and natural for people who work here to use as little energy as possible. Using staircases which are designed to encourage people to walk has a two-way advantage.

It makes the people working there healthier and reduces elevator use. Also, this building promotes bike parking by encouraging human-powered transportation and low-flow fixtures and composting toilets in order to save energy. When we again look at the other factors, using energy-efficient equipment which is smart, and also systems which are energy-efficient and smart were selected to deliver the remaining need for heating, cooling, ventilating, and illumination. Sensors connected to the building's central nervous system monitor light levels, carbon dioxide levels, temperature indoors and outdoors, as well as wind and sun, to control and deliver heating, cooling, ventilation, and illumination efficiently. Fifth is the use of renewable energy. The sunlight that falls on the building and the energy source or sink of the earth beneath it are the only sources of sustainable renewable energy used to operate this building and power the equipment inside. So, in this class, we saw the example of the Bullitt Center in Seattle, which was designed by considering all the passive strategies with informed decisions well in advance.

We also saw some of the features because I did not want to restrict it only to the passive strategies, but also to bring in all that the building has really used to give credit to all that has been done in the building to make it a regenerative building. Because there aren't many net-positive buildings in the world, especially during the time it was built, which was around 2015. So nearly 9 years ago, this building was a net-positive building, generating about 42% more energy than it actually consumed. And this building bypasses the standards of many certifying agencies and is one of its class, which is what it was designed to be. I mean, a building that is designed to last 250 years and be net-positive in a cold climate.

So, with this, we stop today's class, and in the next class, we will look at another climate type and the strategies required for that climate type. Until then, thank you.