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

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Lecture 03

Urban Heat Island

Dear students, in the last class we saw two simple passive techniques. One is on orientation and form, and for the second one we looked at openings, the size, position, and shading devices. But what happens if we do not design bioclimatically? So, today we will have a look at an important subject called urban heat island. What is urban heat island and the impact it can have on our microclimates? So, if you look at these pictures, though they are only indicative, they will give you a brief idea of what an urban heat island is. Now, urban heat islands are heat islands formed along urban centers, which are very typical only for urban centers. And they are not formed along the periphery of the urban areas.

These are areas that are very warm. We will have a detailed look at what UHI is. And if you map urban heat islands, this is the generic trend of urban heat islands. You can see the amount of heat radiated in this map, and you can see the places that are highly urbanized and dense; those areas have more UHI.

So, urban heat islands are a phenomenon that affects urban areas typically where they are notably warmer than the surrounding rural regions. This temperature difference is very pronounced and high, especially at night more than during the day, and particularly when winds are weak under block conditions and notably during the summer and winter seasons. So, when there is very little wind, which is not carrying away the heat that is built up during the day, this phenomenon becomes more prominent. The primary cause of the UHI effect is the modification of land surfaces, while the secondary contribution includes waste heat generated by energy usage. Research indicates that heat islands can be influenced by proximity to different types of land cover, with urban land becoming hotter near barren land and cooler near vegetation.

As population centers grow, they tend to expand their area and increase their average temperature. The term heat island is used to describe any area that is relatively hotter than its surroundings but typically refers to human-distributed areas. Urban areas occupy only

about 0.5% of the earth's land surface but accommodate more than half of the world's population. So, if you look at the major controllers of urban heat islands, you can see that the green-blue strategy plays an important role, such as vegetation, because the major controllers of urban heat islands can be segregated into three.

One is the green and the blue strategy. Second is material strategy, and third is planning strategy. The green and blue strategy refers to vegetation. So there is a need to increase green areas or increase vegetation. Blue infrastructure pertains to water bodies.

Building material strategies include use of high-albedo building materials, more pervious surface area, and cool and green roofs. Planning strategies include urban ventilation as a need for the wind to sweep away the heat and zonal regulations. Now, let us look at the need to study urban heat islands. We have already seen that urban heat island is a phenomenon where a significant difference in temperature can be observed within a city or between a city and its suburbs and/or its surrounding rural areas, and areas of maximum temperature can expectedly be found within the densest part of the urban area. We need to study urban heat island because, first, we are a country of rapid urbanization.

UHI urban heat islands are formed over urban areas, and when we are urbanizing we need to study the impact of urbanization on UHI. Cities accommodate over 50 percent of the world's population and this is expected to still grow beyond Although urbanization has limited effects on climate change, our cities are capable of responding to it, and one of the responses would be to build better heat-resilient cities for the future. Second is public health. Urban heat island does not Urban heat island leads to very high temperatures in urban areas. This increases the risk of heat stress and heat-related issues, including sometimes being fatal.

among vulnerable populations such as children and elderly and those who have a pre-existing health condition. Third is the humongous amount of energy consumed because of urbanization as the buildings become warmer. Air conditioners are used. These air conditioners use the environment as a heat sink and throw away the heat outside, and this causes urban heat islands to further make the external areas extremely hot, further increasing the load on air conditioning. So, it is a vicious cycle.

Fourth is urban planning. It is important to understand urban planning and design and knowledge of urban geometry. This can help in designing buildings and streets that promote and channelize natural wind flow so that there is no stagnation of the heat and the heat gets dispersed. Fifth is air quality. So, higher temperatures inside the urban heat island zone can accelerate a lot of chemical reactions in the atmosphere.

This can lead to increased formation of ground-level ozone, which is a major component of smog. This ultimately results in various respiratory issues. So, it becomes very important for us to study urban heat islands. So, according to TR Oak, there are three scales of interest that we should concentrate on. First is a mesoscale, second is the local scale, and third is microscale.

So, at mesoscale, a city influences weather and climate at the scale of the entire city. So, typically tens of kilometers of extent, and a single station is not able to represent this scale. This is very important because the urban heat island in this area can form like an urban dome, which is very hot. In a hot and humid climate, what happens is only this part becomes so hot. And knowing the humidity, the ability of the air to hold water decreases as it becomes hotter and hotter.

And torrential rain exclusively on urban areas is becoming common these days. One reason for that is attributed to UHI. So, it becomes important for us to study at a mesoscale. Second is a local scale. So, at a local scale, this includes landscape features like topography, morphology of the place, and so on.

So, in urban areas, this translates to mean that the climate of neighbourhoods that have similar types of urban development, like similar surface cover, similar sizes, or similar distances between buildings or areas that hold similar activities, should be studied. So, typical scales can be known from one to several kilometers. Then next, we study at a microscale. So, if you look at local scale, it is very limited in area. Then we study microscale.

So, micro scale what happens is typical scales within the urban microclimate which relate to the dimensions of one or two buildings. between the two buildings, the trees, the roads, the street pattern, the greenery, courtyards, etc. All these are at microscale. So, typically scales extend from less than, say, 1 meter or even up to 100 meters depending on the context. So, we should study at these three scales.

Let us look at the causes and effects of urban heat island. There are two broad categories of factors underpinning the urban heat island intensities. First is the spatial factor. The impacts of changes in the spatial aspects of the urban environment, such as changes in urban form and land cover patterns, on urban heat island intensity are studied as a spatial factor, and the second one is the temporal factor. That is how urban heat intensities vary between different temporal scales, like, say, between years or between two seasons or between a day and night, and so on.

So, there are various causes that affect or affect due to the cause. So, the causes can be

spatial, and spatial causes include the percentage of green cover, the urban density—how much is the built-up area per acre, the population—how many people reside in an acre, the anthropogenic heat-impervious surfaces such as say roads, asphalt roads, surface albedo, the percentage of blue cover, and water bodies that absorb a lot of heat and pace rapid urbanization or pace of urbanization. These are the spatial factors. Temporal factors include diurnal temperature variation and extreme weather events.

It could be the heat events. Whom does it affect, or how does it affect? So, this can affect people, causing heat stress You would have read recently that a number of people have collapsed and died due to heat stress in India and it is a record number in Rajasthan this year. Second is thermal exhaustion, and thermal exhaustion can lead to a lot of damage to the internal body parts. Third is high energy consumption through buildings. in order to keep the indoors cool. The second major effect is on microclimate.

So, how does thermal comfort get affected? Wind patterns tend to change. The ecosystem gets affected. Sometimes migratory birds collapse and fall. I am giving a very small and common example. Heat pressure zones are created, and once they are created and precipitation starts, there can be very heavy rainfall just over a city because of UHI, and that can even cause unprecedented and unexplained rain over cities, causing flooding.

Let us look at the common causes of urban heat island. First is vegetation. Now, due to the ability to produce shade through evapotranspiration and photosynthesis, the vegetation cover plays an important role in cooling cities. Research indicates that when densely populated areas lack vegetation, the intensity of urban heat and its effect can increase by up to 3.8 degrees centigrade to 4 degrees centigrade.

Second is urbanization and building morphology. So, other controllable factors include land cover, building morphology, and city planning. The morphology of buildings has a significant impact on wind flow, solar radiation received on the surface fabric, density, ratio and other factors. The third one is the surface materials. In addition to applying a few planning strategies and optimizing building morphology, the surface materials of walk, walls, roofs, pavements and other structures have properties like thermal emissivity, solar reflectance, albedo, heat-storing capacity, etc.

that can influence the formation of urban heat islands in urban areas. Materials with low emissivity, such as concrete, asphalt, and metals, store heat and release it slowly, causing the heat to be trapped in the energy balance cycle. The fourth is anthropogenic heat. The majority of anthropogenic heat generated in urban areas is produced by human interventions such as vehicles or air conditioning systems or generation of power or industrial buildings. So, in retrospect, the pollutants emitted in the air by these activities

are more likely to be suspended for a longer time than to escape the boundary layer because of urban heat islands.

Other than applying a few planning strategies and optimizing building morphology, this factor of construction is beyond the scope of architects and planners. But in order to reduce this, it is definitely in the hands of architects and planners, because if we are able to design buildings that do not need the source of active energy to cool them, then automatically the anthropogenic heat generated through HVAC systems can be reduced. Similarly, if the planning of cities is done in such a way that transportation between two places is not really needed and people do not have to travel long distances for their day-to-day affairs, then the anthropogenic heat due to vehicles can be reduced. Then we have the meteorological conditions. So, meteorological conditions of wind and cloud cover impact the cause of UHI.

The city conditions with minimal wind and no cloud cover are highly at risk for high intensity of UHI. On the other hand, the windy and cloudy weather conditions reduce the occurrence of UHI. So, the causes of UHI Due to all that we discussed, such as vegetation, urbanization, etc. The reasons, in a nutshell, are waste heat that is generated, use of building materials such as concrete or highly reflective building materials, extremely dense cities forming a cloud of heat, rapid urbanization, and air pollution from industries. And why does the urban heat island effect even occur in cities? It is a known fact that cities are 3 to 10 degrees hotter Studies in India has shown that Indian cities are about 3.

8 degrees to 4 degree Celsius hotter than the rural areas. Even amongst certain pockets of the city, there is a difference of about 2.5 degrees centigrade between one part of the city and the other part of the city. So, it occurs because of heat absorption and retention by the surface, which does not have enough blue and green infrastructure. Plant transpiration and water evaporation from the soil are completely absent due to a lack of vegetation, and water penetration is very low in cities.

So, these are the causes of urban heat islands. Let us look at the impact of urban heat islands. Impact on outdoor thermal comfort and human health. So, the human body is designed to react or respond to the heat in two ways. One is to increase the blood supply to the surface of the skin to dissipate surface temperature, and the second is to release sweat to cool the skin by evaporation.

These responses may result in pressure of oxygen generation on the heart, hence cardiovascular issues, lack of oxygen, heat ingress in cardio systems and hence lung failure, etc. can happen. Mortality rates could increase. In 50 cities of the US, the years between 1989 and 2000 showed that a 5.7 percent increase in mortality rate has happened due to

heat.

In India, there are specific places where the impact of heat stress has increased mortality. Areas near Rajasthan, areas in Rajasthan, New Delhi, Andhra Pradesh, and Orissa have had mortality due to heat stress. This year's mortality is approximately 61 in just Rajasthan alone.

So, this increase of say 4.1 percent to 5.8 percent in mortality rate was observed over 1 degree centigrade of increase over 29 degree centigrade. So, vulnerability. The continuous higher temperature affects mostly humans living in low-insulated homes, people with existing health issues, people working outdoors, such as construction laborers, and places with low cooling appliances. The effect of the urban heat island controllers on outdoor thermal comfort is one of the effective ways to assess and study their effects.

This in turn impacts energy consumption. So, in order to maintain this, in order to maintain human health, in order to ensure that human beings do not succumb to heat stress, there is an increase in energy consumption, which actually means that we are cooling indoors by throwing the heat outside and thus aiding the UHI. Let us look at urban morphology. The urban geometries of buildings do have an impact on the microclimate elements of solar radiation, wind speeds, air temperature, etc. Through multiple researches, the urban fabric factors of building mass, orientation, and density have proven to be climate modifiers. The effects of 2D and 3D building morphology indicators on urban meteorology can be studied in two aspects, in seasonal variations and at different scales.

It was found that the 3D indicators had closer correlations with the outdoor thermal comfort than the 2D indicators. Local climate zones, LCZs. Local climate zone is one of the efforts to segregate urban morphologies into archetypes used for various assessments related to urban climate. The LCZ categorization is based upon the morphological indicators such as height of roughness, elements, and terrain roughness class. This system is a classification that helps in better understanding the differences in thermal performance of different parts of the city.

The dry bulb temperature of about 3 degrees Celsius and the difference in relative humidity of about 15% were recorded in the same city at different locations. And you can see even graphically you can see how the various local climatic zones could probably have an impact on urban heat island, you have a compact high rise setting versus a lightweight low rise setting. It is obvious that UHI is going to be higher here and is going to be low here. There is a compact midrise versus a large lowrise.

So, it is obvious that UHI is going to be higher here. Compact low rise versus sparsely

built with a lot of green vegetation, UHI is going to be high here. Open high rise with vegetation versus heavy industry; it is going to be high here and so on. So, these are relative. So, there are these various conditions that exist in urban areas, and one is better than the other or one is worse than the other in terms of increasing urban heat island. Let us now look at the strategies for mitigating urban heat island.

First and most important are trees and plants. So, by providing shade and cooling through evapotranspiration, an increase in tree and plant cover decreases air and surface temperatures. Additionally, plants and trees help prevent erosion and lessen stormwater runoff. The second is green roofs. We will be looking at green roofs a little in detail later. So, these are sometimes referred to as rooftop gardens or eco roofs, and these have advantages because they provide shade and absorb heat from the atmosphere through evaporate transpiration.

Third is cool roofs. So, cool roofs are composed of materials or coatings that dramatically reflect heat from the sun away from the building. You can minimize energy use, improve occupant comfort, and lower room temperature. Fourth is cool pavements. So, by reflecting more solar energy and increasing water evaporation, paving materials that stay cooler than traditional pavements can be used to improve nighttime visibility, reduce storm water runoff, and cool the pavement surface and surrounding area. And then the last is smart growth, which actually means translates or which can be interpreted as good urban planning principles.

So these practices encompass a variety of development and conservation tactics that contribute to the preservation of the environment while simultaneously enhancing the appeal, vibrancy, and livability of our communities. So, urban heat island can definitely be reduced and its impact mitigated by adopting proper passive techniques in buildings, which will ensure that the demand for or reliance on active energy sources is reduced. So, we will stop our class with this topic and continue with another topic in the next class. Thank you.