Engineering Psychology

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Week-07

Lecture-17

Environmental design - 1

Namaskar. Welcome to this lecture. Today, we will discuss environmental design, which is a crucial aspect of workspace design and plays an important role in the study of engineering psychology. In the past few weeks, we have explored human limitations and capabilities, and how these factors can be used to optimize machine-human interaction. We have studied both cognitive and physiological capabilities, as well as human movement, and other significant factors that help engineering psychologists improve the interaction between machines and humans.

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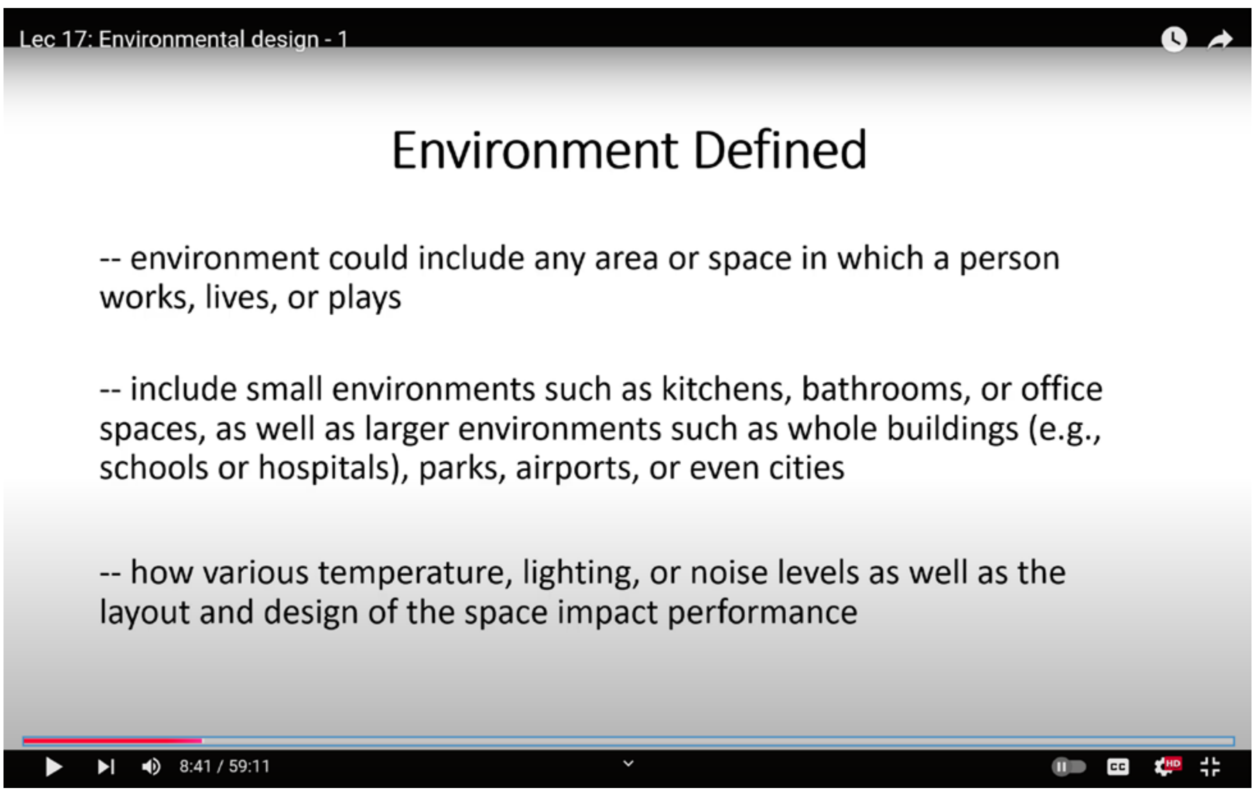

A key element in studying the relationship between humans and machines stems from the design of the environment. Most people perform their tasks within specific environments, and the design of these environments has a significant impact on performance outcomes. Even with optimal human capabilities, a poorly designed environment can lead to reduced performance. Several environmental factors, including temperature, heat, cold, lighting, and spatial design, contribute to the overall performance of individuals. When these factors are appropriately addressed, they can enhance human-machine interaction and lead to better performance outcomes.

To illustrate the importance of environmental design, let me share a small story. Ram Manohar is a sales executive. His job requires him to work both in the office and in the field. There are days when Ram Manohar works in the field, and the constant variations in temperature, both heat and cold, affect his performance and behavior. The outdoor environment can be excessively hot or cold, which negatively impacts his ability to work effectively. Additionally, factors such as noise and the layout of the environment where he works also play a role in influencing his performance.

Let’s imagine that Ram Manohar is scheduled to meet someone at a particular location, and this person shares a map with him to help him find the place. However, the more Ram Manohar consults the map, the more confused he becomes. Eventually, he ends up walking in circles, unable to locate the meeting point. This demonstrates how external environmental factors can influence his performance.

On other days, Ram Manohar works in his office, which is a windowless space cooled by a central air conditioning system. While working on sales-related calculations at his computer, he sometimes finds the office too cold, which hinders his ability to perform his tasks effectively. In addition to this, his workspace, a small cubicle, is surrounded by other people in close proximity. As a result, he often overhears conversations from neighboring cubicles, which can be distracting and reduce his productivity.

Moreover, his windowless office is illuminated by artificial lighting designed to replicate natural light. However, this artificial lighting can sometimes make it difficult for Ram Manohar to concentrate. Working in both indoor and outdoor environments also poses a challenge for him, as he struggles to acclimate to the varying conditions. As design engineers, we must consider what improvements can be made to Ram Manohar's work environment to enhance his performance and satisfaction.

The issues I’ve highlighted form the core of today's lecture and the one that follows. We will explore how temperature, heat, and cold affect cognitive performance, and we will examine the design of work environments in detail. This includes aspects such as interior design, noise levels, wayfinding behavior, and the lighting and illumination of workspaces. I will provide some general guidelines and best practices that, if followed, can lead to improved environmental design for workplaces.

As I mentioned at the start of this lecture, the context in which a person works significantly influences their performance. Therefore, it is essential to consider the design of the environment when evaluating and enhancing human performance in the workplace. Let us now begin by defining what constitutes an environment.

In general terms, people often perceive the environment as the natural world, comprising lakes, parks, trees, people, bicycles, and many other elements. However, when a human factors engineer refers to the environment, it has a broader meaning compared to this common perception. From the perspective of an ergonomist or human factors engineer, the environment can include any space in which a person works, lives, or engages in recreational activities. What I want to emphasize is that the context in which people live their lives constitutes the environment.

The term "environment" does not necessarily refer to natural surroundings, such as those associated with tourism or scenic beauty. Rather, it represents an integral part of a person’s daily life. Throughout the day, humans transition between different spaces, such as offices, homes, and public areas, and they constantly interact with a variety of environments, whether it is the workplace, recreational spaces, or living quarters.

The definition of environment can encompass both small and large spaces. On the smaller scale, it includes kitchens, bathrooms, and office spaces, while on the larger scale, it refers to entire buildings such as schools, hospitals, parks, airports, and even cities. In this sense, the environment spans from microscopic levels, such as individual office cubicles, to macroscopic levels, such as buildings like the Rashtrapati Bhavan or large public areas like railway stations. The environment ranges from small, confined spaces to vast public structures.

Our focus in this section is on how factors such as temperature, lighting, noise levels, and spatial design influence human performance. Temperature, which involves the variations between heat and cold, is just one aspect. Lighting, both natural and artificial, as well as noise, defined as any disruptive sound that affects performance or distracts attention, also play critical roles. All of these factors significantly impact the way people work.

The layout and design of the work environment are crucial to the successful completion of tasks. For example, the placement of the computer keyboard, the distance between the monitor and the user, the positioning of the chair in relation to the desk, and the proximity of the person to colleagues or other objects within the workspace all contribute to the context within which people perform their tasks.

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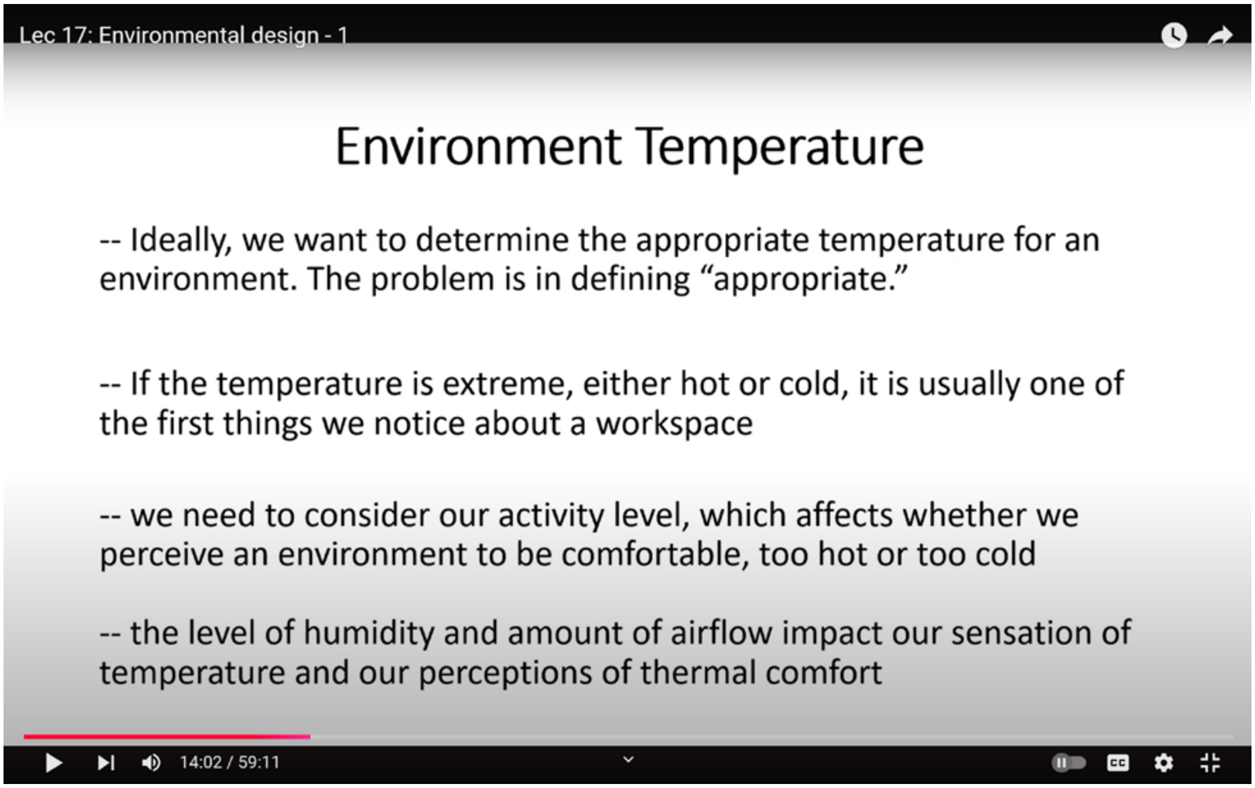

Let us now discuss the first factor: environmental temperature. The temperature of the environment, which refers to the degree of hotness or coldness, is a major factor influencing performance. Ideally, we want to define the "appropriate" temperature for an environment, but the challenge lies in determining what constitutes "appropriate."

People often seek an optimal temperature, whether they are in a cinema hall cooled by air conditioning, where they may feel too cold by the time of intermission, or in a park where the sun suddenly becomes unbearably hot. Individuals will naturally try to counteract uncomfortable temperatures by moving to a place where they feel more at ease. So, what is the appropriate temperature that people desire?

A logical assumption would be that the appropriate temperature is close to body temperature, but is that the actual case? We will explore this further in our discussion. When the temperature is extreme, either too hot or too cold, it is often one of the first things we notice in a workspace. Imagine entering an environment that is either excessively hot or cold; your immediate reaction is discomfort. Excessive heat or cold causes the body to perspire or shiver, which are unpleasant sensations that lead to complaints. Therefore, extremes of temperature are something people strive to avoid.

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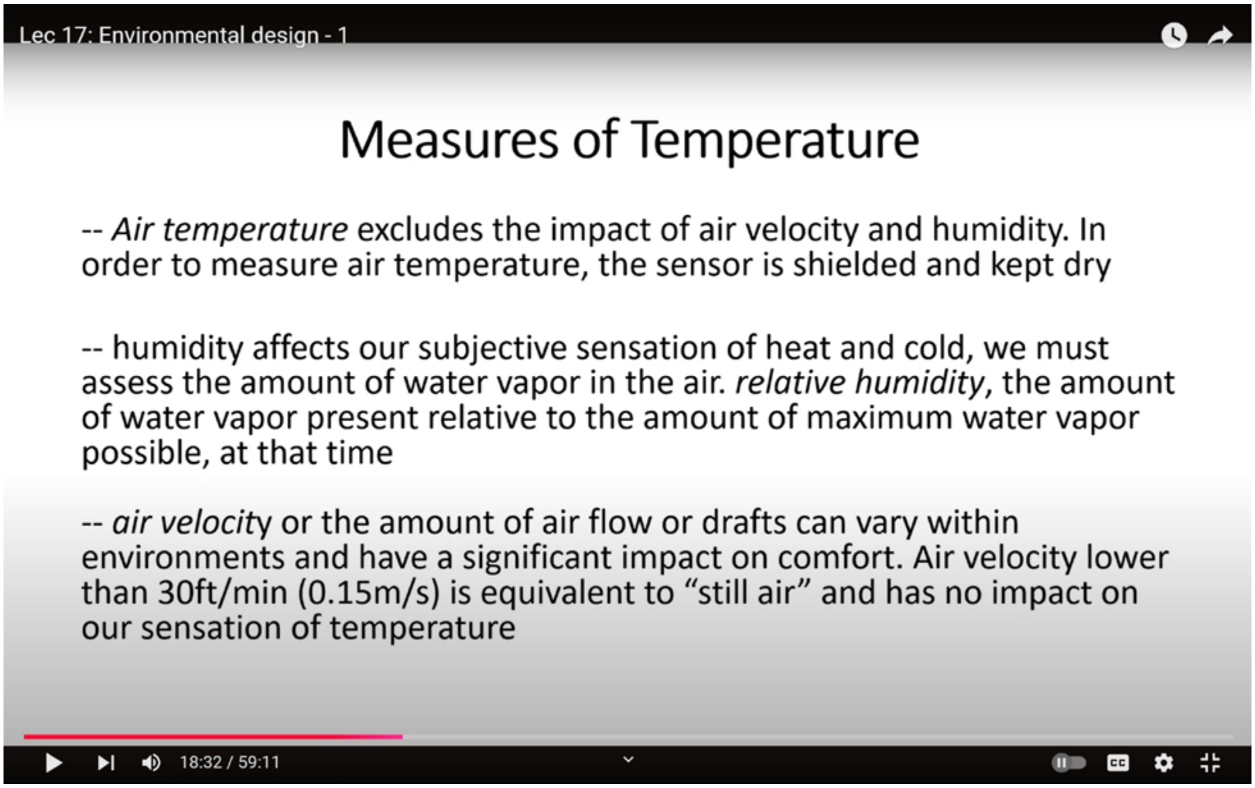

Activity levels also play a crucial role in how we perceive an environment’s comfort. In a cold environment, if a person’s activity level is low, they will feel uncomfortable. However, individuals who are more physically active, such as those moving around an office, generate body heat through metabolism, which helps them feel more comfortable in a cooler setting. Thus, depending on activity level, an environment may be perceived as either comfortable or uncomfortable.

In addition to temperature, factors like humidity and air flow contribute to how we experience thermal comfort. These three elements, temperature, humidity, and air flow, work together to determine whether an environment feels comfortable for working. Let us now look at how temperature is measured.

Air temperature is measured using a dry bulb thermometer, which excludes the effects of air velocity and humidity. The dry bulb thermometer is designed to prevent environmental humidity and air flow from affecting the measurement. It provides a reading of temperature differences in terms of degrees of hotness or coldness, typically measured using mercury pressure.

To measure air temperature accurately, the sensor of the thermometer is shielded and kept dry. However, thermal comfort is influenced not only by air temperature but also by variations in humidity and air flow. Humidity, or the amount of water vapor in the air, affects our subjective experience of heat or cold. The higher the humidity, the more uncomfortable we tend to feel.

Humidity is usually measured in terms of relative humidity, which indicates the amount of water vapor present in the air relative to the air’s maximum moisture capacity at a given temperature. This measurement is crucial because the more moisture in the air, the more it interferes with our ability to regulate body temperature, making us feel uncomfortable.

Relative humidity is defined as the amount of water vapor present in the air relative to the maximum amount of water vapor that the air can hold at a given temperature. If the amount of water vapor in the environment is less than the air's capacity to hold it, this deficit will be filled through processes like evaporation or heat transfer from the person to the environment. When humidity reaches 100%, this transfer of heat or water vapor halts, resulting in stillness. Thus, humidity is an important factor that complements dry air temperature in influencing comfort. Another critical factor that affects our sensation of hotness and coldness is air velocity.

Air velocity, which refers to the speed of airflow or drafts, can vary within environments and significantly impact comfort levels. Imagine situations where there is no airflow, where the air is still, and humidity is high. For instance, during the summer months in eastern India, people often experience discomfort. Although the temperature may not be excessively high, the air is saturated with water vapor and cannot absorb more. In the absence of airflow, people perspire due to their body temperature rising, but since the air is already filled with moisture, this perspiration cannot evaporate, leading to discomfort. In such situations, people tend to seek areas with some air movement, such as near a fan, to feel more comfortable. This movement of air, or air velocity, plays a key role in how we perceive temperature.

Air velocity below 30 feet per minute (approximately 0.5 meters per second) is considered still air and has little to no effect on temperature perception. To feel the effects of air velocity on temperature perception, the airflow needs to exceed 30 feet per minute (0.5 meters per second). Below this threshold, the air is too still to influence how temperature is perceived. Thus, while the thermometer may measure the dry air temperature, human perception of temperature is referred to as "effective temperature," which, as explained earlier, results from a combination of multiple factors.

Effective temperature reflects the combined effects of air temperature, relative humidity, and air velocity. Together, these three factors influence our perception of heat, cold, and overall comfort in an environment. Different combinations of air temperature, humidity, and air velocity can result in the same effective temperature, meaning that by altering one factor while keeping the others constant, or by varying all factors to different extents, people may experience similar levels of comfort or discomfort. This implies that even if the air temperature remains constant, changes in humidity or air velocity can alter people's perception of comfort.

Moreover, objects in our environment also influence how we perceive temperature. Besides humidity and air velocity, objects in our surroundings can affect our sensation of effective temperature. For example, sitting next to an exterior wall during the winter may make you feel the coolness of the wall's surface. This phenomenon is known as the mean radiant temperature. We often experience this when standing near objects that are either hot or cold, our bodies tend to perceive and feel the heat or cold radiating from those objects.

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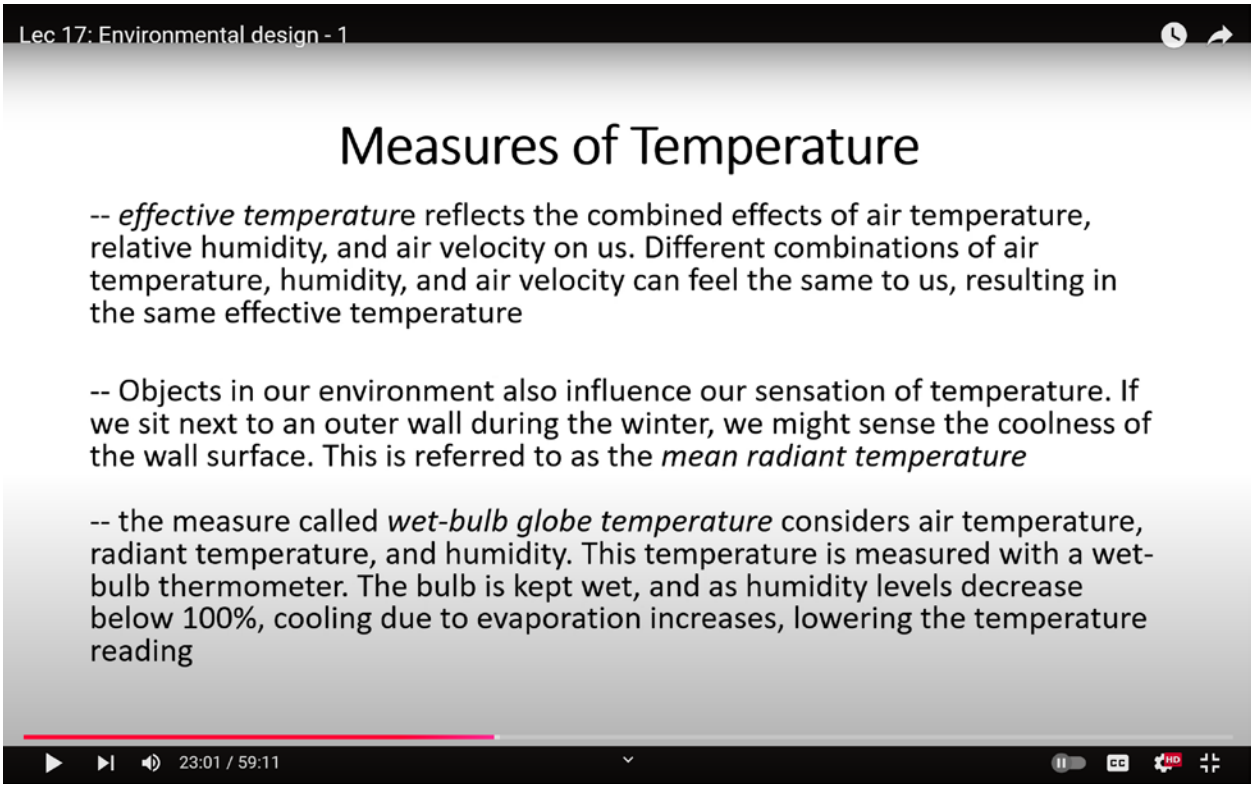

For instance, if it is cold and you are standing near a heated wall, you will begin to feel warmer as heat transfers from the warmer object (the wall) to the colder object (your body) through radiation. Conversely, if you are in a warm environment and the outside is cold, heat from your body will transfer to the cooler wall, making you feel cold. Thus, not only do air velocity, humidity, and temperature impact our perception of heat and cold, but the objects we interact with also play a role in shaping our sense of comfort or discomfort.

The wet-bulb globe temperature (WBGT) measure accounts for air temperature, radiant temperature, and humidity. This measurement is taken using a wet-bulb thermometer, where the thermometer bulb is kept moist to consider the wetness of the environment. WBGT is used to calculate the effective temperature by factoring in air temperature, radiant temperature, and humidity.

The wet-bulb thermometer, by design, has a wet bulb that cools as humidity decreases below 100%, due to evaporation, which lowers the temperature reading. At 100% humidity, there is no evaporation, so the wet-bulb thermometer shows no cooling effect. As humidity decreases, evaporation increases, leading to a drop in the temperature reading, reflecting changes in humidity.

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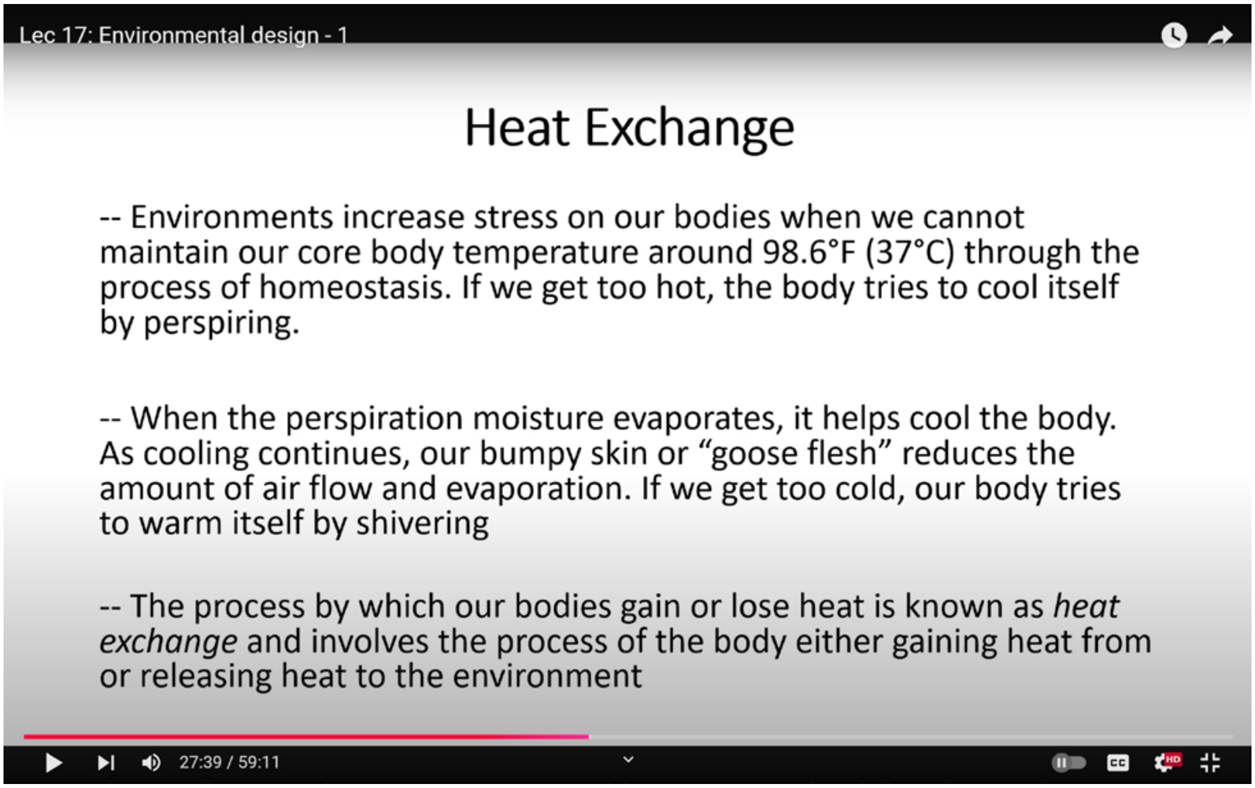

Beyond temperature, the exchange of heat plays a critical role in how we perceive comfort within a working environment. Our bodies are subject to stress when we are unable to maintain a core body temperature of approximately 98.3°F (37°C) through the process of homeostasis. When we become too hot, the body attempts to cool itself through perspiration. The effects of temperature cause the body to either heat up or cool down, leading to an exchange of heat from the body to surrounding objects or the environment, or vice versa.

The human body strives to maintain a core temperature of 37°C, which it regulates through the process of homeostasis, primarily via metabolic activities. When the body becomes too hot, perspiration forms on the skin. This perspiration draws heat away from the skin and evaporates into the environment, transferring heat from the body in the form of moisture droplets. As this process occurs, the skin cools down as heat is exchanged between the body and the surrounding environment.

When perspiration evaporates, it cools the body. As cooling continues, the formation of goosebumps or bumpy skin reduces airflow and evaporation. If perspiration were to evaporate over extended periods, the body might cool excessively. To prevent this, goosebumps appear. When the body reaches a comfortable temperature, these goosebumps or bumpy skin reduce air circulation and evaporation, thereby limiting further perspiration and maintaining a balanced heat exchange. This mechanism helps protect the body from overcooling, even on very hot days.

Conversely, when the body becomes too cold, it initiates shivering to generate heat. Thus, the human body employs natural mechanisms for both heating and cooling. Shivering generates heat, raising the body temperature back to normal, while perspiration cools the body by removing excess heat. This balance ensures that the body maintains an appropriate internal temperature.

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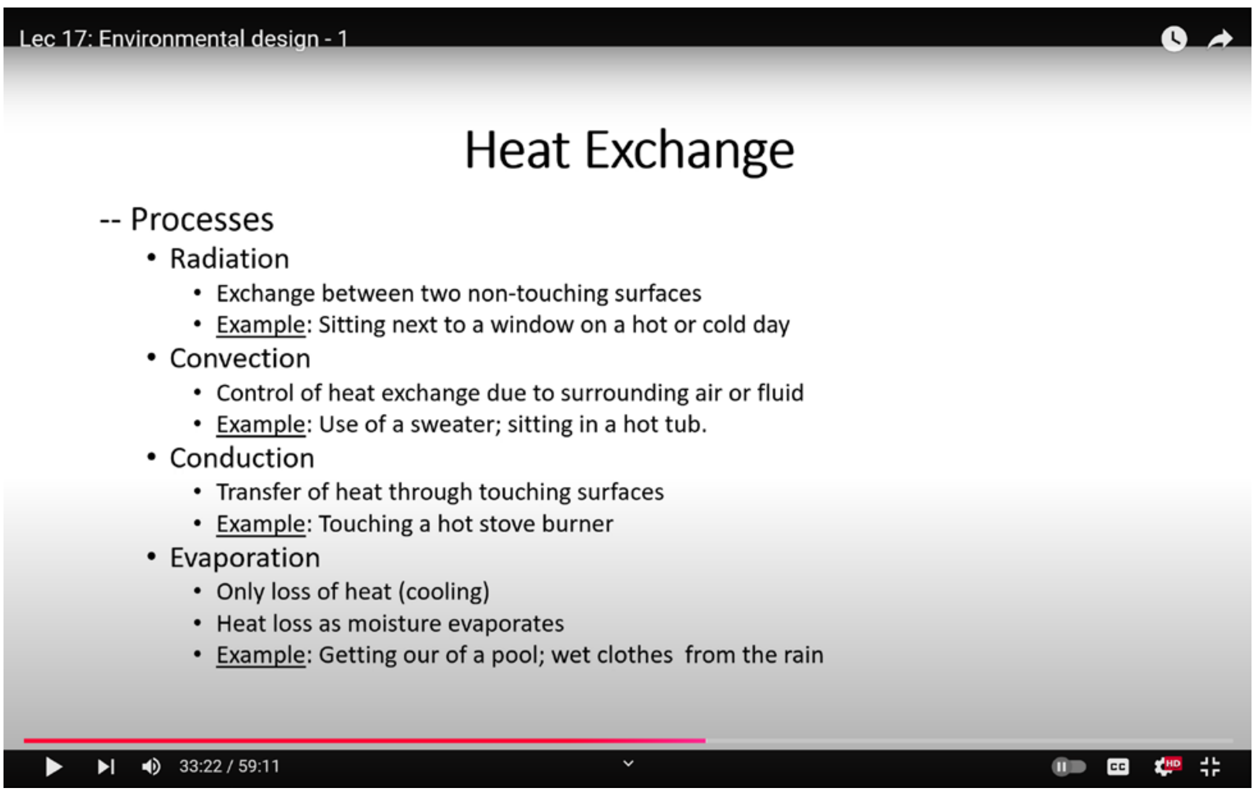

The process by which the body gains or loses heat is known as heat exchange. This involves the body either absorbing heat from or releasing heat to its surroundings. The transfer of heat between the body and the environment can occur through four main mechanisms: radiation, convection, conduction, and evaporation. Each of these plays a significant role in maintaining comfort, and a comfortable body temperature contributes to improved performance and productivity. Let’s explore these processes in detail.

The first mechanism is radiation, which involves heat exchange between two non-contacting surfaces. In radiation, heat is transferred between two objects without the need for a medium. A common example is sitting near a window on a hot or cold day. Even though you are not physically touching the window, you can still feel its warmth or coldness. This sensation is due to the heat exchange between your body and the window’s surface via radiation, with no medium in between.

Another example of radiation is a thermos flask. Since there is a vacuum between the flask's inner and outer layers, it loses heat (or cold) at a slow rate. This loss of heat through a vacuum, without any medium, is also an example of radiation.

The second mechanism is convection, where heat transfer occurs through a medium such as air or fluid. Unlike radiation, convection requires a material to facilitate heat exchange. An example of convection is wearing a sweater or sitting in a hot tub. In the case of a sweater, the warmth of the fabric heats the thin layer of air trapped between the sweater and your body. This heated air, in turn, warms your body. In a hot tub, heat transfers from the hot water to your skin. In both cases, convection allows heat to flow through a medium, air or water.

The third mechanism is conduction, which occurs when heat is transferred between two objects in direct contact. A simple example is touching a hot burner. When your hand touches the burner, heat transfers from the hot stove to your hand, causing you to feel the heat immediately. This transfer of heat through direct contact is known as conduction.

The fourth and final mechanism is evaporation, which results in heat loss through cooling. Evaporation is a one-way process, meaning that it only leads to cooling and not heat gain. During evaporation, heat is carried away as moisture evaporates from a surface. As the air molecules take heat from the evaporating surface and release it into the environment, the surface cools down. A common example is the cooling sensation felt when you step out of a pool or wear wet clothes in the rain. In both instances, evaporation leads to a feeling of coldness as the moisture evaporates from your skin or clothes.

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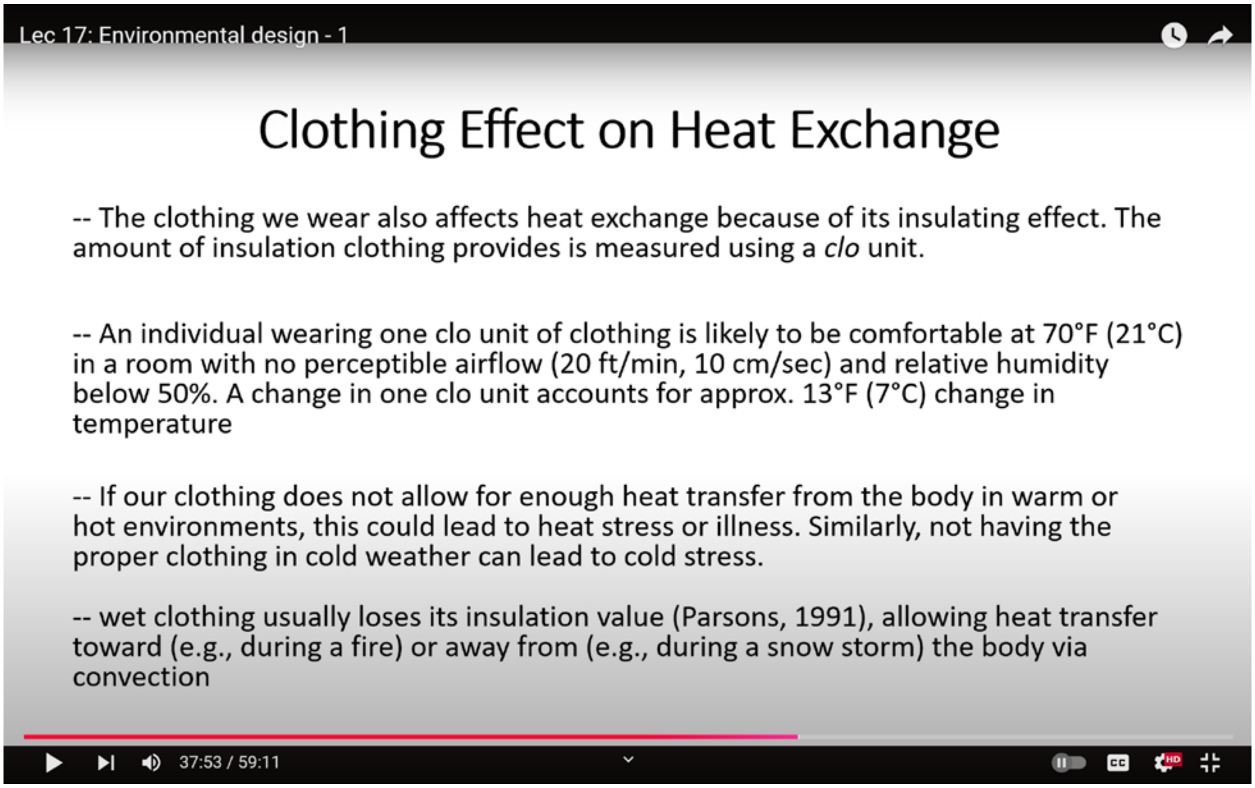

In addition to these mechanisms of heat exchange, clothing also plays a role in regulating body temperature. Clothing acts as an insulator, and the amount of insulation it provides is measured in clothing units (clo). Fabrics differ in their ability to retain or release heat, thereby influencing how much heat the body retains or loses in different environments.

Cotton is a material with excellent conductive properties for heat transfer. On the other hand, artificial materials like polymer-based nylon can retain heat for extended periods, which can lead to discomfort. Cotton, being a highly breathable fabric, promotes better heat exchange, making it a preferred choice for clothing. This heat exchange facilitated by clothing is measured in clo units. But what exactly is the clo unit, and how is this measurement carried out?

To explain, an individual wearing one clo unit of clothing is likely to feel comfortable at 70°F (21°C) in a room with minimal air flow, which is around 20 feet per minute (10 cm/s), and relative humidity below 50%. Thus, a person dressed in one clo unit of clothing will generally feel comfortable at this temperature, even with 50% humidity and still air. As the clo unit increases, so does the body's insulation, with one additional clo unit corresponding to a temperature variation of about 13°F (7°C). So, as layers of clothing increase, the overall clo units increase, resulting in corresponding changes in body temperature.

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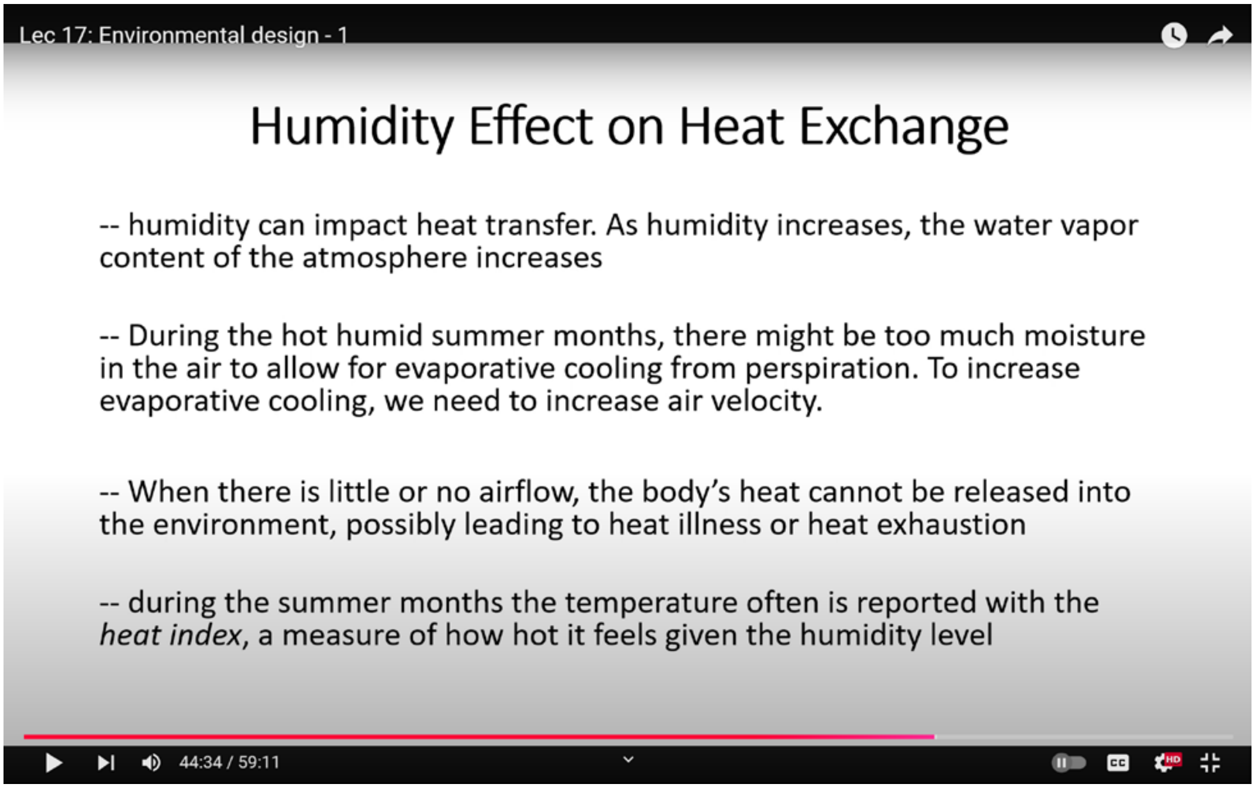

With each additional clo unit of clothing, there is a 7°F variation in perceived temperature. However, if clothing does not permit adequate heat transfer from the body in warm environments, it can lead to heat stress or related illnesses. Similarly, inadequate clothing in cold weather can cause cold stress. Today, many fabrics available are blends, often combining cotton with polymers such as nylon or terry cotton.

When cotton is blended with synthetic materials, its natural properties are altered. These changes affect how efficiently cotton retains or releases heat. This alteration in cotton's structure due to blending can significantly impact its rate of heat transfer. If the fabric blend does not allow for quick heat dissipation in warm conditions, or sufficient heat retention in cold temperatures, it can cause heat stress or discomfort. For example, wearing synthetic fabrics in winter may cause excessive heat retention, leading to perspiration. When sweat becomes trapped between the body and the clothing, the body's temperature can rise even during cold weather, eventually leading to discomfort and heat flushes.

Therefore, selecting appropriate clothing is crucial, especially for workers, as clothing plays an integral role in heat exchange. Wet clothing, in particular, loses its insulating properties. In conditions like fires or snowstorms, wet clothing may allow heat transfer toward the body (in a fire) or away from it (in cold conditions) via convection. This loss of insulation makes it important to use wet clothing with caution in such situations.

Similarly, humidity also affects heat exchange. As humidity increases, the air becomes saturated with water vapor, reducing the ability of perspiration to evaporate and cool the body. In hot, humid environments, excessive moisture in the air hinders evaporative cooling, which can cause discomfort. To enhance evaporative cooling, increased air velocity is necessary. For instance, in humid work environments, proper ventilation through fans or air ducts is often used to facilitate air movement, thereby helping evaporate sweat more quickly from the skin and enhancing comfort.

When there is little or no airflow, the body cannot efficiently release heat to the environment, which may result in heat-related illnesses or exhaustion. Insufficient heat exchange can lead to serious health concerns, especially in hot, humid conditions. During the summer, the heat index, a measure that combines air temperature and humidity, helps predict how hot it feels. This heat index is commonly referenced in weather forecasts. It accounts for the raw temperature changes in combination with humidity levels, giving a more accurate representation of how the temperature feels to people.

It's possible for the temperature to feel comfortable, yet high humidity can cause discomfort. Conversely, a high temperature with low humidity may still feel comfortable due to better evaporative cooling from perspiration. For example, on a cloudy day with high humidity, people often feel uncomfortable even if the temperature is not particularly high. On sunny days, however, higher temperatures can feel more bearable when humidity is low.

Airflow also plays a significant role in heat exchange. Fans, for instance, are frequently used during hot and humid summer months to increase air velocity, which enhances evaporation and promotes heat loss, thereby cooling the body. In regions with high humidity and little temperature variation, increased airflow is essential to ensure comfort by facilitating heat exchange.

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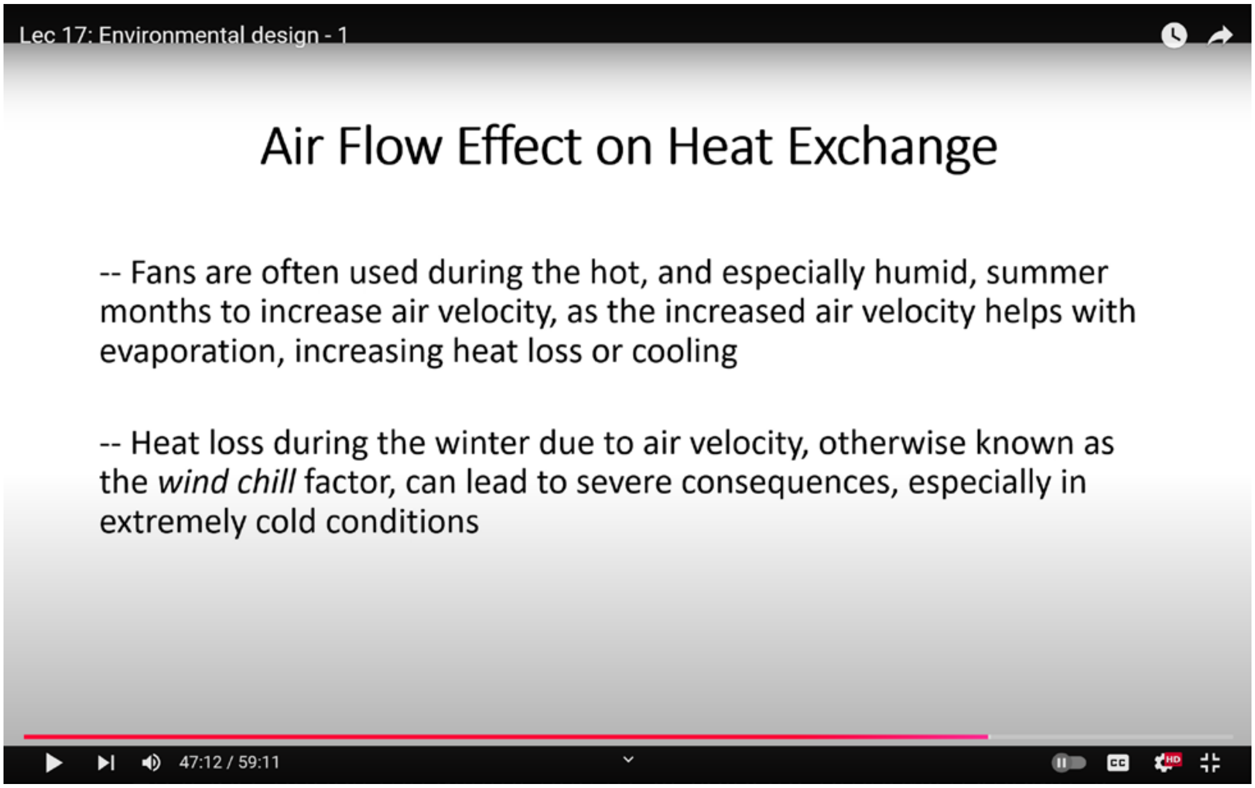

Your air conditioner likely has a setting for humidity control. This setting allows the air conditioner to circulate air without cooling it, which helps people feel more comfortable. Humidity control can be achieved through airflow, and this movement of air can improve heat exchange. During winter, heat loss due to air movement, also known as the wind chill factor, can lead to serious consequences, especially in extremely cold conditions. The loss of heat in winter due to wind chill can cause significant problems.

Excessive heat gain or loss can result in heat-related illnesses. Prolonged exposure to extreme heat can lead to heat stress or heat-related illnesses. Symptoms of heat illness include fatigue, cramps, heat rash (also known as prickly heat), and in severe cases, heat exhaustion or heat stroke. Signs of heat stress include excessive sweating, increased heart rate, and elevated core body temperature.

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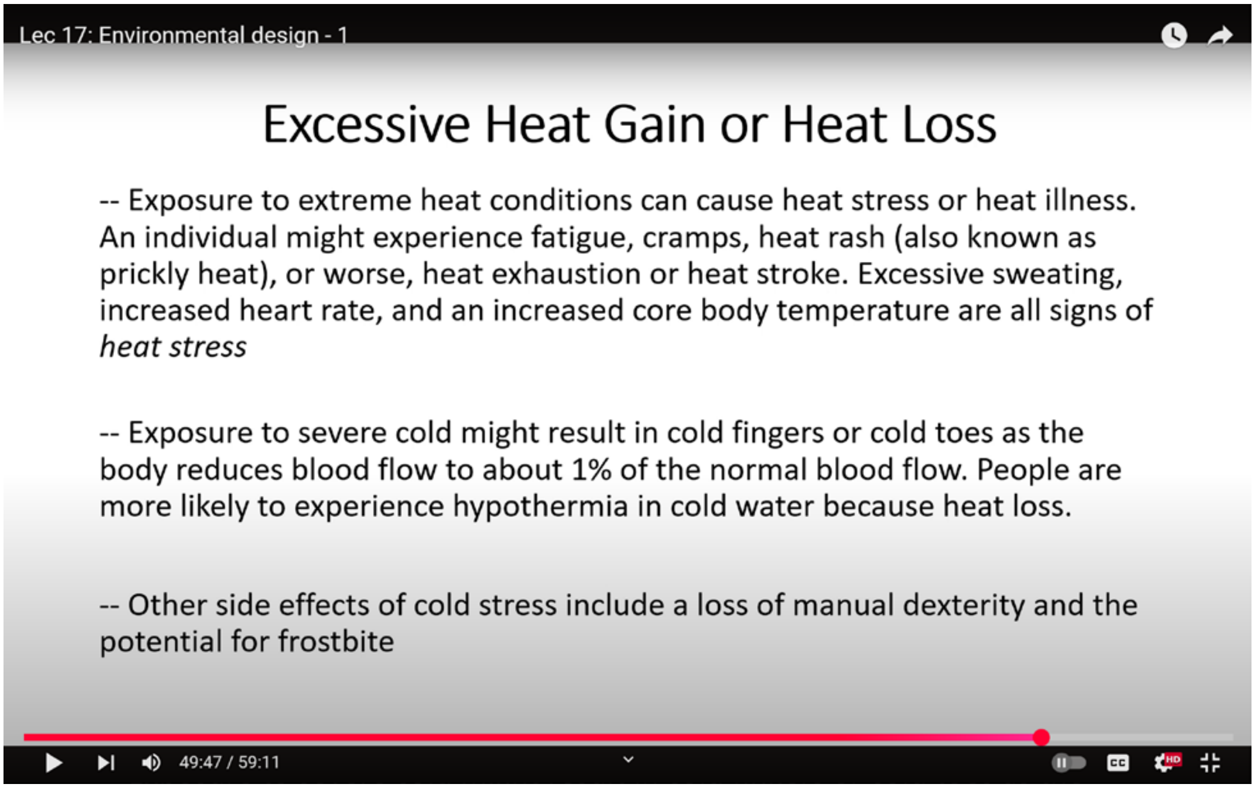

Excessive heat not only causes physical discomfort, such as fatigue and cramps, but also cognitive decline or decreased cognitive workload. Exposure to severe cold can result in cold fingers or toes, as the body reduces blood flow to these areas to about 1% of normal. People are more likely to experience hypothermia in cold water due to rapid heat loss. In extreme cold, excessive heat loss or cold stress can cause other issues, including loss of manual dexterity and the potential for frostbite.

If the body loses too much heat, cold stress can also impair manual dexterity, which can affect the performance of physical tasks and increase the risk of frostbite. Two terms, acclimatization and acclimation, are often used to describe how the body adjusts to different temperatures. Let's explore the difference between these two.

Acclimatization refers to the process by which individuals exposed to cold or hot conditions over an extended period (about one to two weeks) become better adapted to those environmental conditions. People who remain in a specific environment for a longer time, whether cold or hot, become acclimatized. On the other hand, if individuals frequently move between different environments, they do not become acclimatized. For instance, think of entering a cold, dark cinema hall and then stepping out into a warm, bright environment. You immediately feel the difference. This rapid transition between environments is referred to as acclimatization or the loss of acclimatization. However, if you work in the cinema hall, the cold environment may no longer affect you.

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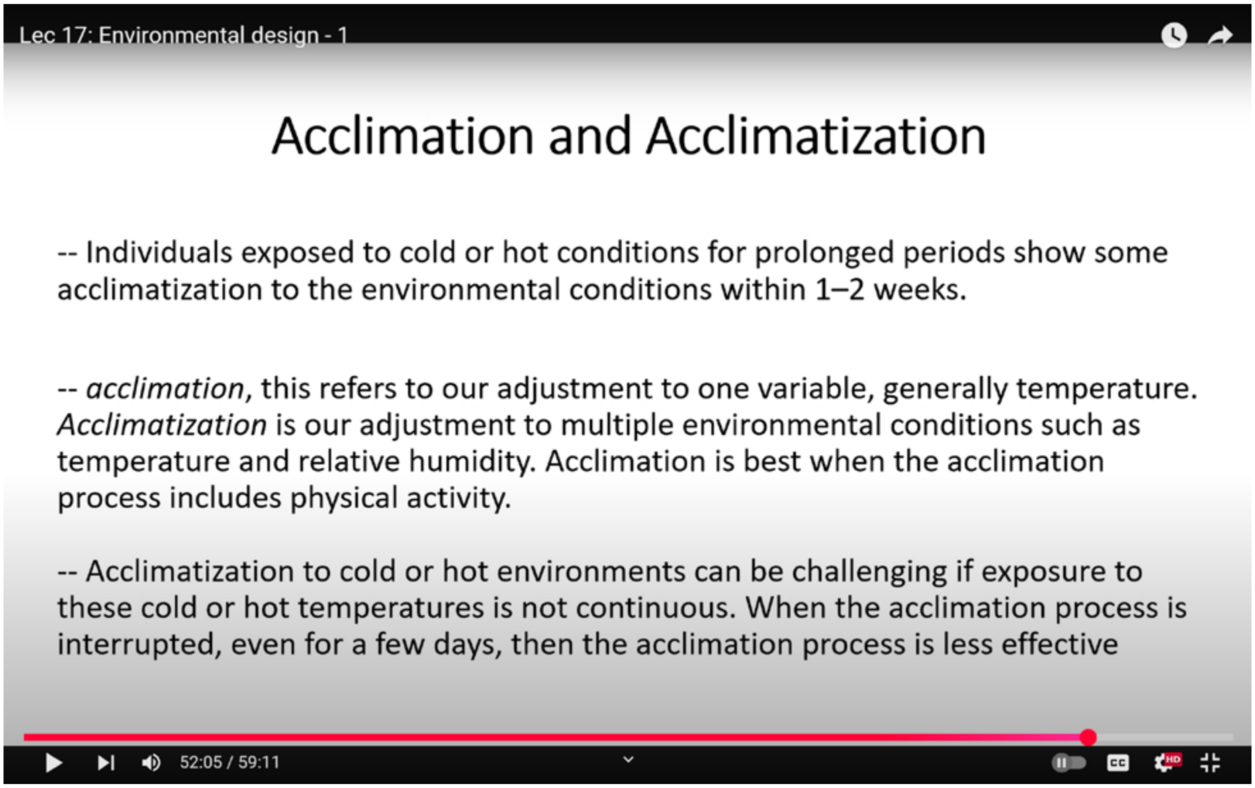

Visitors to the cinema, who only experience the cold once in a while, will notice the temperature change more acutely. Acclimation, on the other hand, is the body's adjustment to a single variable, typically temperature. Acclimatization, in contrast, involves adjustment to multiple environmental factors such as temperature, humidity, and airflow. Acclimatization is most effective when the acclimation process includes some form of physical activity. While acclimation pertains specifically to temperature adjustment, acclimatization involves adapting to an environment that consists of multiple factors.

This process of acclimation is most effective when some level of physical activity is involved. Acclimatization to extreme cold or hot environments can be challenging, especially when exposure is not continuous. When the acclimatization process is interrupted, even for a few days, it becomes less effective. If you regularly switch between environments, your body adapts to both, and the transition becomes less stressful. However, infrequent shifts between environments can cause discomfort. Think again of the cinema worker who regularly moves in and out of the cold theater. Since they frequently transition between both environments, they have adapted and no longer feel as much stress on their body.

In contrast, cinema-goers, who move between environments infrequently, experience more stress on their bodies when they move from a cold theater to a hot outdoor environment, or vice versa. Continuous movement between different environments allows for faster acclimatization.

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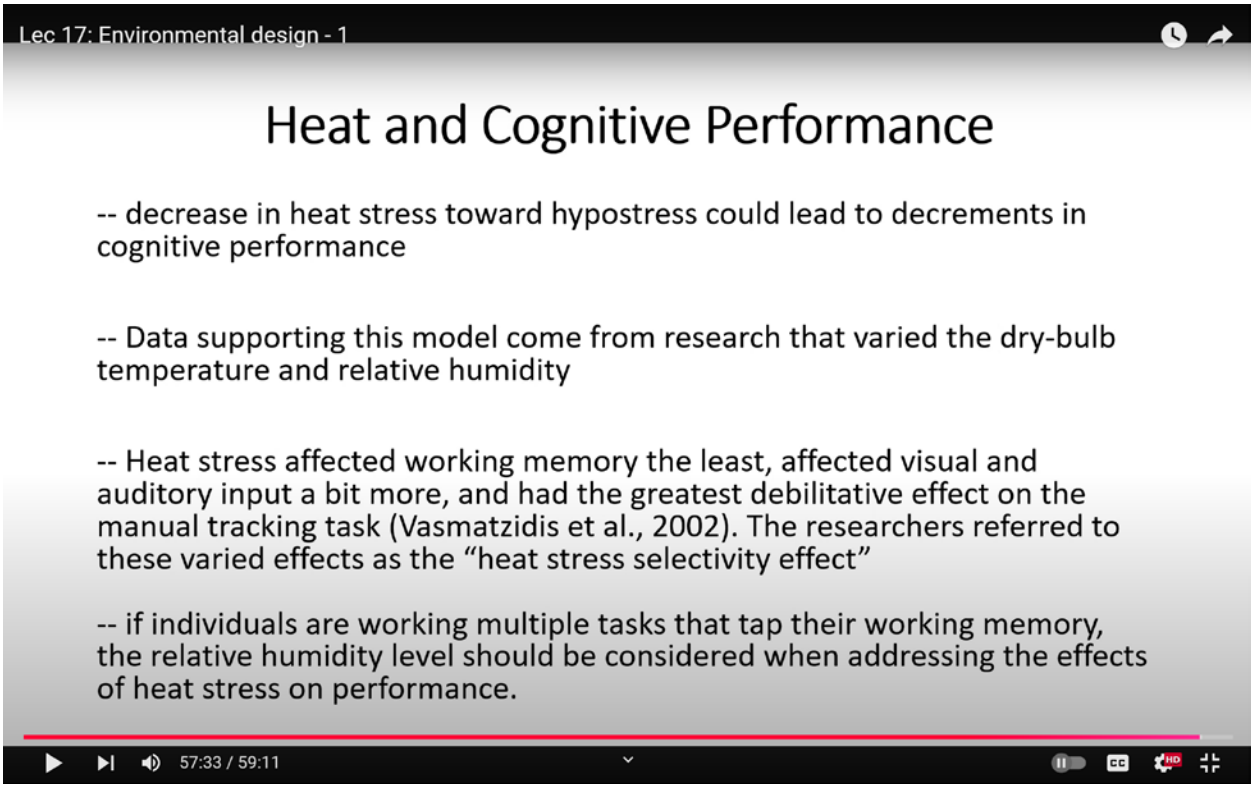

Heat can also lead to a decline in cognitive performance. But what kind of cognitive decline does heat cause? Let's explore this. In some cases, heat causes a decline in performance, while in others, performance may remain unaffected or even improve. Reaction time for simple motor tasks typically remains unchanged during heat stress, while more complex tasks, such as vigilance, tracking, and multitasking, are more affected by heat. Higher-order cognitive tasks, such as attention and vigilance, are more impacted by heat stress compared to simpler tasks like motor responses.

One explanation for why more complex tasks are affected by heat stress is that heat reduces our ability to focus on multiple tasks. Heat diverts or manipulates our attention, making it harder to concentrate on the factors necessary to perform higher-order cognitive tasks effectively.

The maximum adaptability model suggests that as stress, such as heat, either decreases or increases, performance declines due to a reduction or depletion of attentional resources. According to this model, when the stressor, such as heat, increases toward the hyper-stress level, performance declines well before any physiological problems manifest. In other words, under conditions of hyper-stress, individuals may experience cognitive fatigue long before they feel physically exhausted. This means that various performance impairments will appear well in advance of severe physiological effects due to heat stress.

Similarly, a decrease in heat stress towards hypo-stress, or lower stress levels, can also lead to a decline in cognitive performance. Research supporting this model has shown that varying the dry bulb temperature and relative humidity affects performance. In these experiments, changes in temperature and humidity were applied, and the participants' performance was evaluated under different conditions.

The results showed that heat stress had the least impact on working memory, while it had a moderate effect on visual and auditory inputs, and the most significant impact on manual tracking tasks. Higher-order cognitive tasks like working memory were least affected by heat stress, while visual, auditory, and tracking tasks were more strongly impacted. The researchers referred to these differential effects as "heat stress selectivity effects."

If individuals are performing multiple tasks that involve working memory, it is important to consider not only the heat but also the relative humidity levels and airflow when assessing the impact of heat stress on performance. For jobs that involve multiple cognitive functions, both heat and humidity should be accounted for when evaluating worker performance in varying thermal conditions.

In today's lecture, we explored temperature, heat exchange, and the effects of heat on cognitive performance. In future lectures, we will examine the impact of cold on cognitive performance and other environmental factors, such as noise levels, lighting, and spatial arrangements, and how these elements influence human performance. That’s all for today. Namaskar and thank you. Amen.