Textile Product Design and Development
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Lecture - 16
Thermal Comfort

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We are going to discuss thermal comfort and the conditions that contribute to it. First, the body must maintain heat balance, which is a crucial requirement. Next, the sweat rate should fall within comfortable limits, and the mean skin temperature must also remain within those limits. The heat balance is necessary but not sufficient conditions for comfort.

The body could be in heat balance but uncomfortably hot due to sweating. If sweat production is too high, discomfort will result. Conversely, the body may feel uncomfortably cold due to vasoconstriction and low skin temperature. The key points to remember are that heat balance must be maintained, the sweat rate should be within comfortable limits, and the mean skin temperature must also fall within acceptable ranges.

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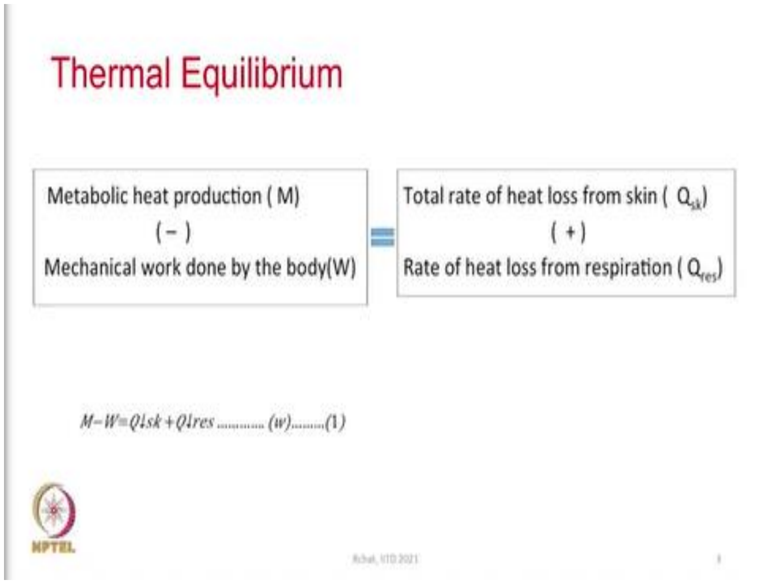

Next is the concept of thermal equilibrium. The body continuously generates heat, known as metabolic heat. This metabolic heat production is denoted as 'M'. The energy is provided by the metabolic heat that the body generates. Therefore, the net heat within the body can be expressed as

$$Metabolic\ heat\ production\ (M) - Mechanical\ work\ done\ by\ the\ body\ (W)$$

This energy expenditure for mechanical work can involve various activities, such as walking, sitting, reading, jogging, or playing essentially any activity except sleeping. The difference between metabolic heat production and the energy spent on mechanical work results in excess heat within the body. This excess heat must be dissipated, and it should equal the total rate of heat loss from the skin, denoted as 'Q_{sk}', along with the rate of heat loss from respiration.

Since we continuously breathe in air and exhale it, there must be a balance between the heat generated in the body and the heat lost. The excess heat within the body should be balanced by the heat loss through the skin and the heat lost due to respiration. Mathematically, it is represented by

$$M - W = Q_{sk} - Q_{res}$$

where 'M' represents metabolic heat production, 'W' denotes mechanical work done, 'Q_{sk}' is the heat loss from the skin and 'Q_{res}' is the heat loss due to respiration.

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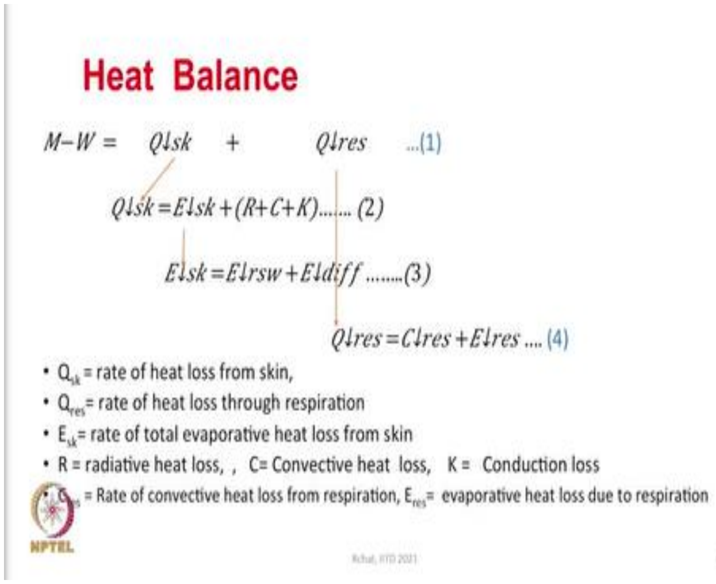

There are various ways through which heat can escape from the skin. From our earlier equation '$M - W = Q_{sk} - Q_{res}$' , we can express 'Q_{sk}' using another equation '$Q_{sk} = E_{sk} + R + C + K$'. In this equation, '$E_{sk}$' represents the heat lost through evaporation from the skin, which comprises two components: 'E_{rsw}' the evaporation loss due to sweating and 'E_{diff}', the evaporation loss due to diffusion. Similarly, 'Q_{res}' consists of two components. They are 'C_{res}' and 'E_{res}'. It is stated that 'Q_{sk}' represents the rate of heat loss from the skin, while 'Q_{res}' indicates the rate of heat loss through respiration.

Additionally, 'E_{sk}' denotes the total evaporation heat loss from the skin and the other components of 'Q_{sk}' are represented by '$R + C + K$'. Here, 'R' stands for radiative heat loss, which occurs as the body continuously loses heat through radiation. 'C' represents convective heat loss. Because air is taking away part of the heat from our body as it blows over the skin. Additionally, 'K' represents conductive heat loss. Although air is a poor conductor, it still conducts some heat, resulting in minimal heat loss through conduction. The term 'C_{res}' refers to the rate of convective heat loss from respiration, while 'E_{res}' signifies evaporative heat loss associated with respiration.

These equations outline the various components of heat loss from the body. To calculate the total heat loss, we need to assess each of these losses individually and then sum them up. Finally, we must determine whether the total loss on the right-hand side of the equation equals, exceeds, or falls short of the heat balance represented on the left-hand side.

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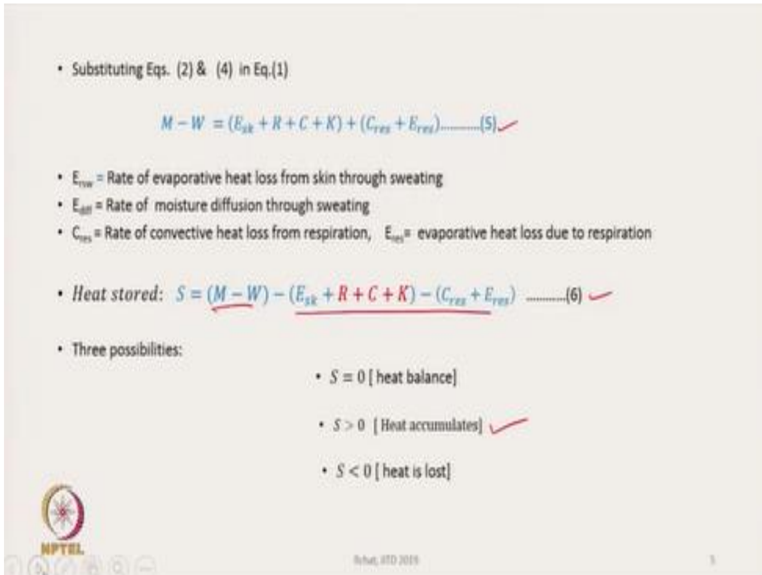

Substituting equations 2 and 4 into equation 1 allows to express the relationship as

$$M - W = (E_{sk} + R + C + K) + (C_{res} + E_{res})$$

This leads to equation 6, which highlights that any imbalance between the heat generated by the body and the residual heat after performing work, compared to the potential heat loss under specific circumstances, is crucial to understand. This is because the amount of heat lost from the body will depend significantly on environmental conditions.

There is often a likelihood of imbalance, which is the case most of the time. Consequently, the difference between the heat generated and the heat lost will lead to a change in the heat stored in the body. This stored heat is denoted as 'S'. If the system is in balance, then 'S' will equal 0. This is thermal equilibrium, and the person will feel comfortable.

When 'S' is greater than 0, it means the body is losing less heat than it is generating, resulting in heat accumulation. As a consequence, the skin temperature rises. This increase in skin temperature can lead to discomfort. When 'S' is less than 0, it means the body is losing more heat than it is generating, which typically happens in colder environments, like during winter. In that case, the body is going to lose more and more heat than it is generating per unit time. As a result of that, the body temperature will decrease.

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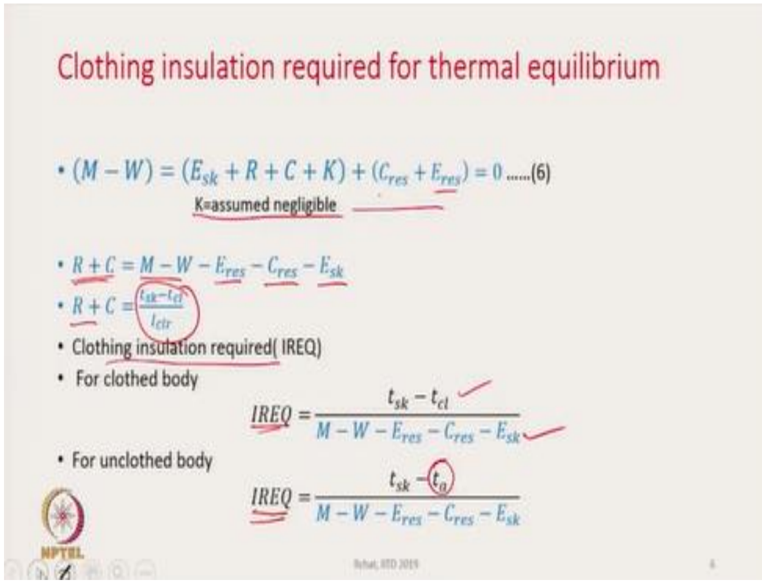

Therefore, clothing insulation required for thermal equilibrium is 'S' has to be 0. This corresponds to the same equation (equation 6) previously discussed. Heat loss through conduction is generally minimal because air is a very poor conductor and acts as an insulator. Hence, for practical purposes, assume that 'K' is so small that it can be neglected from the calculations.

The equation is

$$M - W = (E_{sk} + R + C + K) + (C_{res} + E_{res})$$

Heat loss due to radiation and convection '$(R + C)$' is equal to

$$M - W - C_{res} - E_{res} - E_{sk}$$

'$(R + C)$' should be equal to

$$\frac{t_{sk} - t_{cl}}{I_{Clr}}$$

where 't_{sk}' represents the skin temperature, 't_{cl}' represents the clothing temperature and 'I_{Clr}' represents the insulation value of the clothing material. Thus, if the body is covered by clothing, which provides some insulation, the heat loss due to radiation and convection combined is determined by the temperature difference between the skin and clothing, divided by the insulation value of the clothing material.

Hence, '$R + C$' will be equal to the difference between the skin temperature 't_{sk}' and the clothing temperature 't_{cl}' divided by the clothing insulation. Therefore, for a clothed body, the clothing insulation required will be '$IREQ$'. This '$IREQ$' represents the required clothing insulation, which is essential; 'I_{Clr}' (the clothing insulation value). The equation becomes,

$$IREQ = \frac{t_{sk} - t_{cl}}{M - W - C_{res} - E_{res} - E_{sk}}$$

Where '$R + C$' is the total heat loss from radiation and convection, which corresponds to

$$M - W - C_{res} - E_{res} - E_{sk}$$

For a clothed body, the insulation required '$IREQ$' is determined by the temperature difference between the skin and clothing. For the unclothed body, the body is naked; in that case, the clothing temperature is replaced by the air temperature, which is represented by

$$IREQ = \frac{t_{sk} - t_a}{M - W - C_{res} - E_{res} - E_{sk}}$$

This equation helps to calculate the insulation needed when no clothing is present. These formulas are essential for estimating the insulation value required for clothing under various conditions, whether clothed or unclothed. When designing clothing, especially for winter garments, the first step is determining how much insulation is required to maintain thermal comfort. Once the insulation requirement is established, the next step is to decide on the appropriate materials. This involves selecting the right fibre type, fabric construction, and fabric areal density (g/m^2) to achieve the desired insulation. the design process begins with understanding the insulation needs.

Often, the basic requirements for designing clothing may not be immediately available. In such cases, the designer must gather these requirements through research or analysis. Qualitative requirements, which are not scientific, and technical requirements, are often unavailable. For example, if someone says, "I need clothing that protects me from the cold of Delhi," this is a qualitative requirement, not scientific or technical.

In this scenario, if a company is developing a jacket to protect someone from the cold experienced in Delhi during winter, the key task is determining the actual Clo value required for the jacket. The Clo value represents the thermal insulation provided by clothing. The customer will not specify this technical value; they will only communicate the general need, such as wanting to stay warm in Delhi's winter.

The designer and the design team need to know the technical knowledge of the requirements. Once the required Clo value is identified, the next step is figuring out how to achieve that insulation level in the fabric or garment.

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Some exercises to apply the equations and concepts discussed in previous lectures will be a practical way to understand how to calculate design parameters or variables.

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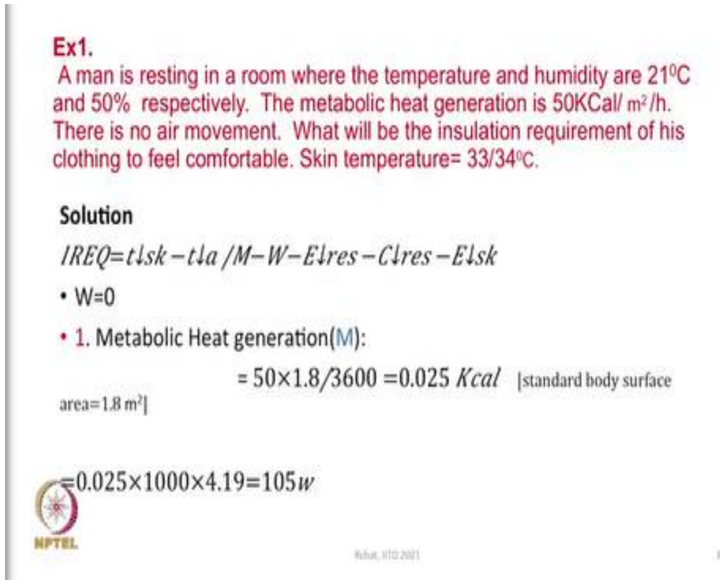

Let us begin with this example: a scenario where a man is resting in a room with a temperature of 21˚C and a humidity level of 50%. The metabolic heat generation is 50 kCal/m^2/h, and there is no air movement in the room. To find out the clothing insulation required for him to make comfortable. Let us assume his skin temperature, which generally varies between 33°C and 34°C, is chosen to be 34°C.

The definition of Clo is that to make a person feel comfortable, if he is sitting in such a room where the temperature is 21˚C and he is generating body heat, which is 50 kCal/m^2/h, then the insulation that he needs to feel comfortable is known as 1 Clo. We know that the insulation requirement ($IREQ$) is calculated using the formula

$$IREQ = \frac{t_{sk} - t_a}{M - W - E_{res} - C_{res} - E_{sk}}$$

In this case, since the person is not doing any work, the value of 'W' is 0. Thus, we must find the metabolic heat generation in watts, given as 50 kCal/m^2/h.

The standard body surface area is generally taken as 1.8 square meters. While individual body shapes and heights can cause variations in this value, 1.8 square meters is the standard used for calculations. To determine the heat generated per second, it is calculated as

$$\frac{50 \times 1.8}{3000}$$

This calculation gives the metabolic heat generated in kilocalories per second for the entire body. This has to be converted into watts. We know that 1 kilocalorie equals 1000 calories, and 1 calorie equals 4.19 joules. Therefore, if we multiply the calories by 4.19, we get joules per second, also known as watts. So, the calculation for the heat generated will be that heat in watts is

$$\left(\frac{50 \times 1.8}{3600}\right) \times 1000 \times 4.19$$

This results in approximately 105 watts of heat generated by the entire body. Thus, if the person is resting, he will generate this heat.

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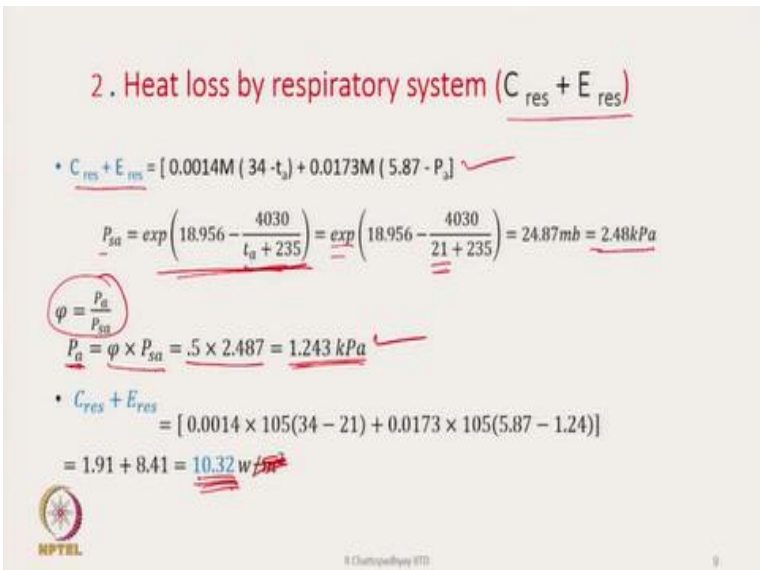

Next is to determine the values of 'E_{res}' and 'C_{res}' from the previous equation. The value of 'M' (the metabolic heat generation) is already found. To find 'E_{res}' and 'C_{res}', the empirical equation has been given, which states that

$$C_{res} + E_{res} = [0.0014M(34 - t_a) + 0.0173(5.87 - P_a)]$$

where 'P_a' is the vapour pressure and 't_a' is the ambient temperature. To find 'P_a', we need to connect 'P_a' and 'P_{sa}' using the formula related to relative humidity.

Given that the relative humidity is 0.5, 'P_a' can be determined once 'P_{sa}' is found. The relationship is given by

$$P_a = \varphi P_{sa}$$

where, 'P_{sa}' gives the saturated vapour pressure in the environment that a person stays in. This is the equation used

$$P_{sa} = exp^{\left(18.956 - \frac{4030}{t_a + 235}\right)}$$

where 't_a' is the temperature of the room, which is considered to be 21˚C. Hence, in this equation, 't_a' is replaced by 21 to calculate the value. This gives a saturated vapour pressure of approximately 2.48 kilopascals (kPa) near the skin at this air temperature. This value represents the saturated vapour pressure on the skin.

From this, the value of 'P_a' is found using the earlier relationship with relative humidity. In a normal state, the vapour pressure 'P_a' can be calculated as '$P_a = 2.487 \text{ x } 0.5$'. This gives the vapour pressure in kPa. This can be substituted along with the temperature values into the equation to find '$C_{res} + E_{res}$', this gives the result of 10.32. This indicates the impact on the respiratory system; as the person breathes in and out, they draw in cold air at a temperature of 21°C.

When the person inhales, cold air is drawn, entering the lungs and absorbing heat from the body, causing its temperature to rise. This process heats the cold air. At the same time, moisture is also released when breathing out. As we exhale, a significant amount of moisture exits through the nose, which is a common occurrence. For instance, we often notice fogging on our spectacles, especially during winter, due to this moisture in the exhaled air.

The fogging effect occurs because the moisture vapour released through the nose during exhalation condenses on the cooler surface of the glasses, creating a foggy layer. In this process of breathing in and out, we also lose a certain quantity of heat. The total heat loss due to respiration can be quantified in watts, representing the thermal energy being exchanged with the environment during inhalation and exhalation.

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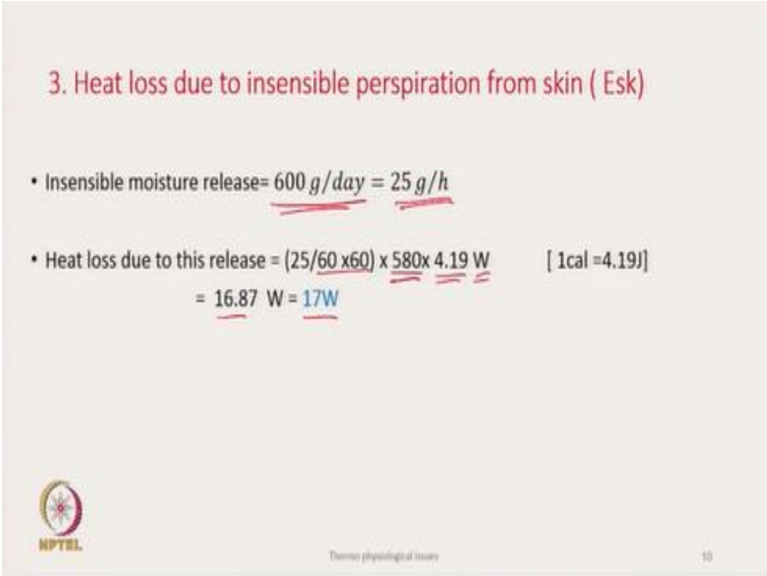

Additionally, moisture is continuously generated from the skin through diffusion. On average, it is reported that about 600 grams of moisture escape from the skin each day, which equates to approximately 25 g/h. To convert this to a per-second basis, it is equal to '$\frac{25}{3600}$' which is approximately equal to 0.00694 g/s. Next is converting the moisture loss into heat using the latent heat of vaporization, which is approximately 580 calories per gram.

When we convert this to joules, we multiply by 4.19 to obtain the heat loss in watts, equivalent to 16.87 watts. Thus, the body loses approximately 17 watts of heat due to the generation of insensible moisture from the skin, which often goes unnoticed. While there is also heat loss due to radiation, it is unnecessary to calculate that for this situation.

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- $IREQ = t_{sk} - t_a / M - W - E_{res} - C_{res} - E_{sk}$

- $IREQ = t_{sk} - t_a / 105 - 0 - 17 - 10.32 = 34 - 21/105 - 27.3 = 13/77.7 = 0.167\ {}^{o}C\ m^2/w \cong 1.07\ clo$

To find the insulation requirement ($IREQ$) using the equation, we can substitute the known values. We have the metabolic heat generated by the body (105 watts); work done ($W = 0$); heat loss due to respiration (E_{res} is 17W); The total heat loss ($E_{res} + C_{res}$) is 10.32W. Given that '$t_{sk} = 34$' and '$t_a = 21$', therefore, '$t_{sk} - t_a = 13$'. Substituting in '$IREQ$' gives 0.167. This insulation requirement ($IREQ$) of approximately 0.167 m^2˚C/W indicates the amount of insulation needed for the clothing so that only 77.7 watts of heat can be lost, ensuring comfort.

When we convert this value, we find that it is equivalent to about 1.07 Clo, which is close to 1 Clo. Therefore, to ensure comfort for the individual in the given conditions, the clothing must provide around 1.07 Clo of insulation. This may vary slightly from person to person because metabolic heat generation may also vary from person to person.

To summarize, in a scenario where a person is sitting in a room at a temperature of 21˚C without any clothing and with a skin temperature of 34˚C and a relative humidity of 50%, the required insulation to ensure comfort is clothing whose insulation will be either 0.167 m^2˚C/W or which is equivalent to 1.07 Clo, which is close to 1 Clo. Another example is designing an ensemble for a person that achieves a Clo value of 1.20. An ensemble is a collection of garments and the sum of the multiple layers of garments that a person wears.

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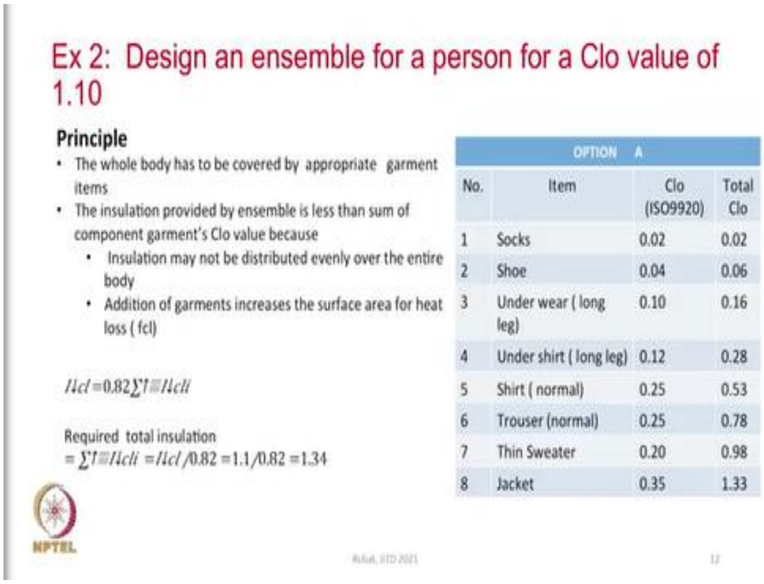

To design an ensemble for a person with a Clo value of 1.10, First, it is essential to remember that the entire body must be covered with appropriate garments. A human body is not just a point; it has both length and width dimensions. Therefore, the entire body needs to be dressed adequately. The insulation provided by the complete outfit is typically lower than the sum of the Clo values of the individual garments. This is important because if we know the Clo values of the items we usually wear, we can select them individually and add them together.

The ensemble Clo value can sometimes be lower than the sum of the Clo values of the individual garments because insulation may not be distributed evenly across the body, and adding more garments increases the surface area for heat loss. Therefore, it is important to use the following equation: the total ensemble Clo value (I_{cl}) is equal to 0.82 times the sum of the Clo values of the individual items (I_{cli}). This equation is derived from empirical studies conducted by standard institutions.

If this is accurate, the total required insulation can be determined. Specifically, the sum of the individual Clo values 'I_{cli}' can be calculated as

$$I_{cli} = \frac{I_{cl}}{0.82}$$

For example, if 'I_{cl}' value is assumed to be 1.1, then the total insulation value is approximately equal to 1.34.

The total insulation value of the individual items must reach 1.34 Clo; this is the required amount. To achieve this, we have selected a set of garments to cover the entire body. A person will need the following items: socks, shoes, underwear, an undershirt, a shirt, trousers, a sweater, and a jacket. The values are presented in the table represented.

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DRY THERMAL INSULATION VALUES

		GARMENT	THERMAL INSULATION CLO
1	UNDERWEAR		
2		Panties	0.03
3		Under pant with long legs	0.10
4		T-shirt	0.09
5		Shirt with long sleeves	0.12
6		Panties & bra	0.03
	SHIRT / BLOUSES		
7		Short sleeve	0.15
8		Light weight long sleeves	0.20
9		Normal long sleeves	0.25
10		Flannel shirt , long sleeves	0.30
11		Light weight blouse , long sleeves	0.15
	TROUSERS		
12		Shorts	0.06
13		Light weight	0.20
14		Normal	0.25
15		Flannel	0.28
	DRESSES / SKIRT		
16		Light skirt (summer)	0.15
17		Heavy dresses (winter)	0.25
18		Light dress short sleeve	0.20
19		Winter dress , long sleeve	0.40
20	BOILER SUIT		0.55

DRY THERMAL INSULATION VALUES

	GARMENT		THERMAL INSULATION CLO
	SWEATERS	SLEEVELESS VEST	0.12
21		THIN SWEATER	0.20
22		SWEATER	0.28
23		THICK SWEATER	0.35
24	JACKETS	LIGHT SUMMER JACKET	0.25
25		JACKET	0.35
26		SMOCK	0.30
27	HIGH INSULATIVE FIBRE SPELT	BOILER SUIT	0.90
28		TROUSERS	0.35
29		JACKET	0.40
30		VEST	0.20
31	OUTDOOR CLOTHING	COAT	0.60
32		DOWN JACKET	0.55
33		PARKA	0.70
34		FIBRE PELT OVERALL	0.55
35	SUNDRIES	SOCKS	0.02
36		THICK ANKLE SOCKS	0.05
37		THICK LONG SOCKS	0.10
38		NYLON STOCKINGS	0.03
39		SHOES (THIN SOLED)	0.02
40		SHOES (THICK SOLED)	0.04
41		BOOTS	0.10
42		GLOVES	0.05

These values are derived from American standards, which studied the Clo values of garments on manikins. Corresponding thermal insulation values have been assigned to various items, including underwear. In this table, a selection of garments such as underwear, shirts, trousers, dresses, skirts, boiler suits, sweaters, and jackets can be found. A total of 42 items and their respective thermal insulation values are listed. This table serves as a database for selecting garments that will adequately cover the entire body and achieve our desired insulation value of 1.34. The following items, such as socks, shoes, underwear, undershirt, shirt, trousers, a thin sweater, and a jacket, can be chosen, and corresponding Clo values for these items have been sourced from the table. Adding these values together gives a total of 1.33, which is very close to the target of 1.34.

This means that by selecting these items, the entire body is almost fully covered except for a few areas. The head, particularly the face and nose, as well as the palms, remain uncovered. These areas can be addressed later if necessary. With the chosen garments, a total insulation value of 1.33

is achieved. Therefore, these standard Clo values are selected from the table, and it is concluded that this represents the ensemble. We have selected eight items in the ensemble to achieve a total Clo value of 1.33, ultimately resulting in an effective Clo value of 1.1. Additionally, it is possible to choose different combinations of items that could yield alternative results.

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OPTION A			
No.	Item	Clo (ISO9920)	Total Clo
1	Socks	0.02	0.02
2	Shoe	0.04	0.06
3	Under wear (long leg)	0.10	0.16
4	Under shirt (long sleeve)	0.12	0.28
5	Shirt (normal)	0.25	0.53
6	Trouser (normal)	0.25	0.78
7	Thin Sweater	0.20	0.98
8	Jacket	0.35	1.33

Option B			
No.	Item	Clo (ISO9920)	Total
1	Thick long Socks	0.10	0.10
2	Shoe	0.04	0.14
3	Under wear(long leg)	0.10	0.24
4	Undershirt (long sleeve)	0.12	0.36
5	Flannel Shirt (long sleeve)	0.30	0.66
6	Trouser (lightweight)	0.20	0.86
7	Sleeve less vest	0.12	0.98
8	Jacket	0.35	1.33

In this slide, options A and B, which consist of eight items, are given, which yields a total Clo value of 1.33. However, there are some differences in the items selected. For example, instead of the regular socks used in Option A, we have chosen thicker long socks in Option B, which have a higher Clo value. In the table for Option B, the items highlighted in red indicate the changes made. In Option B, the normal shirt is replaced with a flannel shirt that has a higher Clo value. The trousers have also changed from regular ones to lightweight trousers, which have a slightly lower Clo value. Additionally, instead of the thin sweater, it has a sleeveless vest with a Clo value of 0.12, which is lower than the previous option. The jacket remains the same in both options, resulting in a total Clo value of 1.33 for both Option A and Option B. There could also be a potential Option C with different item selections.

There are various possibilities for selecting items to arrive at the desired total Clo value. This process allows the design of the ensemble to be effective. By knowing the Clo value of the ensemble, this table can be referred to choose the appropriate items. These garments are generally standardized and have been tested on manikins, with the resulting values provided by recognized institutions. Thus, this table serves as a valuable database for the selection process.

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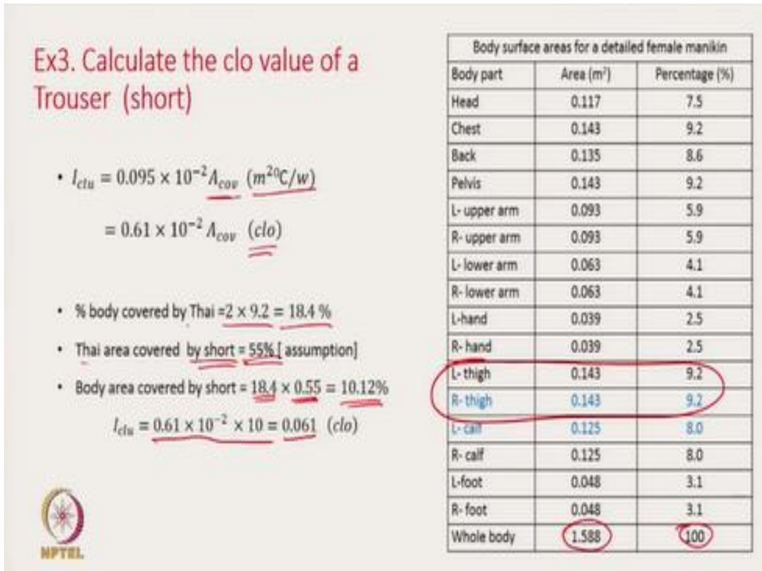

Next, the Clo value for a pair of short trousers is calculated. To determine the Clo value, the following empirical equation is used

$$I_{Clu} = 0.095 \times 10^{-2} A_{Cover}$$

where 'A_{Cover}' represents the percentage of the body area covered. This equation is expressed in terms of $m^{2\circ}C/W$. To convert this to Clo, 0.095 has to be divided by 0.155. Using this formula, the Clo value for short trousers can be calculated. In this case, the trousers primarily cover the thigh area, which accounts for approximately 18.4% of the body. Therefore, for developing a pair of shorts, it is estimated that the percentage of body area covered by the shorts will be around 18.4%. This means that the focus has to be on the thigh area when considering the insulation value provided by the shorts.

However, the entire thigh area will not be covered by the shorts since they are designed to be short. It is assumed that approximately 55% of the thigh area will be covered by the shorts. Therefore, the body area covered by the shorts can be calculated as '18.4×0.55' times, resulting in about 10.12%. This means that the shorts will cover around 10% of the entire body area, as represented in this particular table, which is based on a female manikin. The total body area of the manikin is

1.588, and this data has been given with respect to a manikin; it is considered to be 100. Accordingly, the different parts of the manikin area are quoted in this table. This table can be used to obtain an initial estimate of the Clo value for the short trousers. Consequently, the shorts will cover only 10% of the total body area.

Therefore, the insulation value can be calculated as

$$I_{Clu} = 0.095 \times 10^{-2} \times 10$$

Since 10.12% of the body area is covered, this results in a Clo value of approximately 0.061 for the short trousers. Using this equation, it is found that the shorts provide a Clo value of around 0.06. When considering the standard table, it is found that the value is close to 0.06, although it may vary slightly. If the trousers are a bit longer and cover more of the thigh, the Clo value may increase accordingly. The important thing is the amount of body area that is covered by the garment. Therefore, it is essential to determine the specific body area being covered and the total body area.

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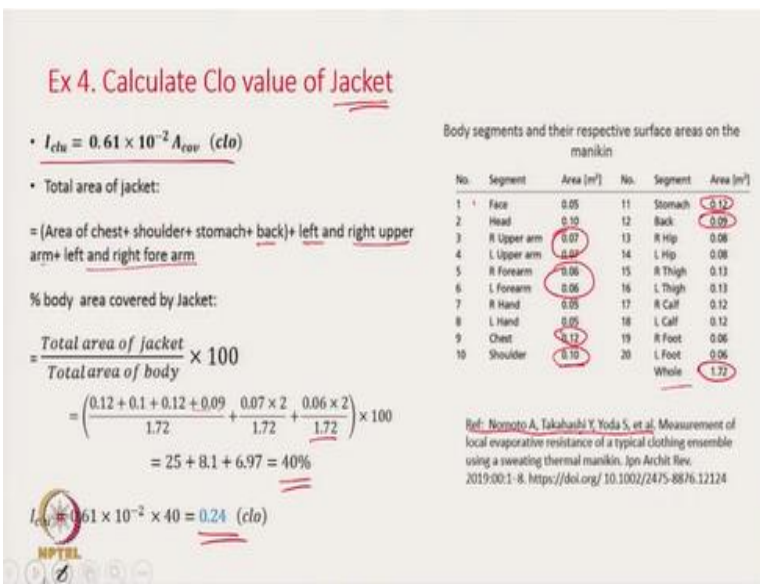

Another example is calculating the Clo value for a jacket. To determine the Clo value of a typical jacket, the table on the right side provides details about various body areas based on a manikin. This table outlines the areas of different body parts, labelled from 1 to 20, allowing us to assess the coverage provided by the jacket. This information is sourced from a research paper authored by these individuals, and it is used to calculate the Clo value for a jacket. The first step is to determine the body area that the jacket covers. The total area covered by the jacket includes the chest, shoulder, stomach, and back, as well as both upper arms and forearms. Considering the design features of a jacket, the area it covers can be identified. A jacket does not extend to the thighs or legs. Instead, it typically covers the front of the body down to the waist or slightly below, the back, and the entire arms.

Therefore, the first thing to do is to determine the specific body area covered by a typical jacket. Next, the corresponding values will be collected from this table. The percentage of body area covered by the jacket is calculated by dividing the total area of the jacket by the total body area. The values for the chest, shoulders, stomach, and back are from this table. These values are indicated here, and to express them in proportion, each area has to be divided by 1.72, representing the total body area. Typically, a standard value of 1.8 is used; however, this manikin has a value of 1.72. or the left and right upper arms, the value of 0.07 is taken and multiplied by 2. Similarly, for the left and right forearms, a value of 0.06 is taken and multiplied by 2. Then, by dividing the total by 1.72 and multiplying by 100, it is found that the jacket covers approximately 40% of the body area. Using this value in the equation yields a Clo value of about 0.24.

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Dry thermal insulation values

	GARMENT		THERMAL INSULATION CLO (I_{clu})
	SWEATERS	SLEEVELESS VEST	0.12
21		THIN SWEATER	0.20
22		SWEATER	0.28
23		THICK SWEATER	0.35
24	JACKETS	LIGHT SUMMER JACKET	0.25
25		JACKET	0.35
26		SMOCK	0.30
27	HIGH INSULATIVE FIBRE SPELT	BOILER SUIT	0.90
28		TROUSERS	0.35
29		JACKET	0.40
30		VEST	0.20
31	OUTDOOR CLOTHING	COAT	0.60

The Clo value for a light summer jacket is 0.25, as shown in the table. There are three types of jackets specified: 0.25, 0.30, and 0.35, which matches the calculated value of 0.24. This provides an initial estimate of the jacket's insulation value. Another important consideration is the thickness of the fabric. A jacket made from a thinner material will have a different Clo value compared to one made from a thicker fabric, as the thickness directly impacts insulation properties. However, this particular equation does not account for the fabric thickness, which should also be considered. For normal fabrics, the equation may provide a reasonable estimate, but for a thicker material, it will likely affect the Clo value significantly.

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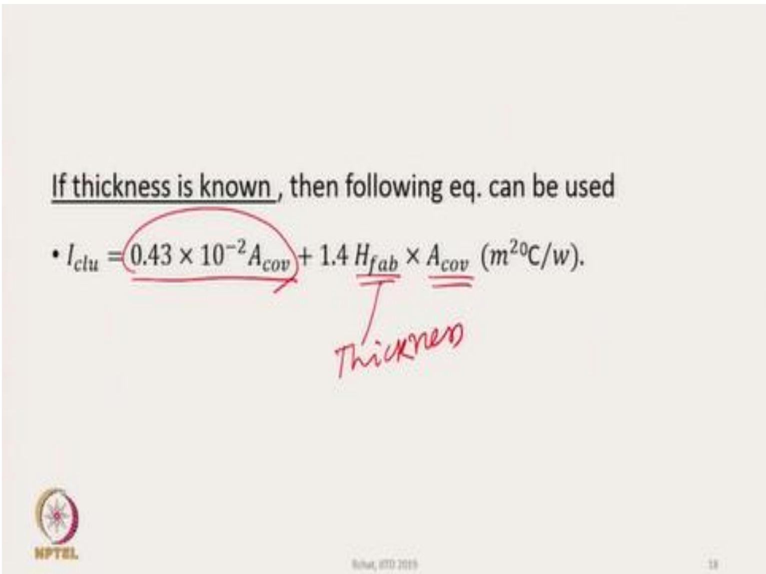

For the calculation of the Clo value for the jacket incorporating the thickness of the fabric, the modified formula is

$$I_{Clu} = 0.43 \times 10^{-2} A_{Cov} + 1.4\, H_{fab} \times A_{Cov}$$

where 'A_{Cov}' is the percentage of the body area covered by the garment and 'H_{fab}' is the thickness of the fabric. This equation allows us to account for both the coverage area and the thickness of the material. The multiplication by 'A_{Cov}' indicates the percentage area covered. This allows us to relate thickness to areal density (g/m^2). To accurately measure thickness, it is essential to follow a specific standard, which dictates the amount of pressure to apply when taking the measurement. By using this standard, the thickness value can be determined from this thickness value, and the percentage area that the garment covers, as well as the insulation value of a garment made from that particular fabric, can be calculated.

The insulation value varies based on the garment design if the fabric remains the same. For example, if a short trouser is made from the fabric, the insulation value will be lower. Conversely, using the same fabric to make a long trouser will produce a higher insulation value. Similarly, a sleeveless sweater made from that fabric will have less insulation, whereas a sweater with sleeves will provide greater insulation.

The Clo value signifies the insulation a fabric provides when it is made into a garment. This value indicates the insulation capacity of the fabric in its garment form, which depends on how much of the body area is covered. If less area is covered, the Clo value will be lower; if more area is covered, the Clo value will increase. However, when examining the fabric in isolation, its properties remain unchanged. The intrinsic insulation value of the fabric itself remains constant. However, once the fabric is transformed into a garment, the insulation value will vary depending on the amount of body area covered by that garment. This approach allows us to utilize various equations to determine insulation requirements in specific situations and helps design an ensemble.

The Clo value of a garment can be determined. Though examples related to thickness are not provided, if the thickness and the percentage of body area covered by the garment are known, then insulation values can be calculated. These examples are intentionally simplistic and aid in understanding. However, it is important to note that these scenarios primarily involve the exchange of dry heat. However, when moisture is involved, an additional dimension must be considered. These factors will be addressed in future lectures. Thank you.