**Textile Product Design and Development**
**Prof. R. Chattopadhyay**
**Department of Textile and Fibre Engineering**
**Indian Institute of Technology - Delhi**

**Lecture – 18**
**Designing Cold Weather Clothing**

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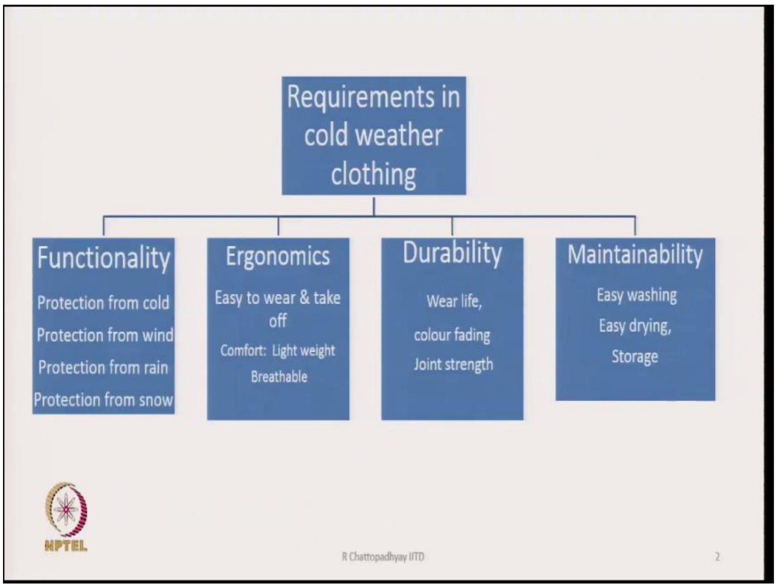


This lecture focuses on designing cold-weather clothing. To begin with, understanding the key requirements is essential, which can be categorized into four groups: functionality, ergonomics, durability, and maintainability. From a functionality perspective, the primary consideration is protection from cold, which is essential in winter conditions. Protection from cold is the primary requirement, followed by protection from wind, especially when stepping outside in winter when there is a wind blowing.

Additionally, protection from rain is important, as winter rain can occur, and in snowy regions, protection from snow is also essential. These are the main requirements from the functionality point of view. From an ergonomics perspective, the clothing should be easy to put on and take off quickly. Comfort is a key factor, and it depends on many parameters. the important two parameters are the weight of the garment and breathability. It should be light because heavy garments are generally not preferred. The fabric should allow air circulation so that the wearer does not feel suffocated, whether worn for a short or long time.

Additionally, there are ergonomic requirements to consider, such as ensuring the garment does not restrict limb movement. In this way, the garment must be designed to allow the person to work comfortably. Another crucial requirement is durability, particularly the wear life of the fabric. Additionally, colourfastness is important. if the colour fades over time, it can negatively impact the aesthetic appeal. Even if the product remains functional, consumers may reject it simply because it no longer looks good.

Another important aspect is the strength of the various joints in the garment. Since multiple pieces of fabric are sewn together to make the garment. These joints should not fail under stress. Hence, the strength of the joints should be strong enough to withstand these stresses. For example, if buttons are present, then there should be repeated failures at these points. If it fails, then it indicates a lack of durability. Next is maintainability, which includes factors like ease of washing, which is important whether garments can be washed in a machine or require special care. Another key factor is drying time.

In some cases, quick drying can be an important requirement. Storage is another aspect of maintainability, whether the garment is easy to store or requires special conditions, such as specific boxes or space, to prevent damage. Another concern is whether the garment will be susceptible to insect attack. This is especially important for designing cold-weather clothing, and each and every aspect has to be taken into consideration.

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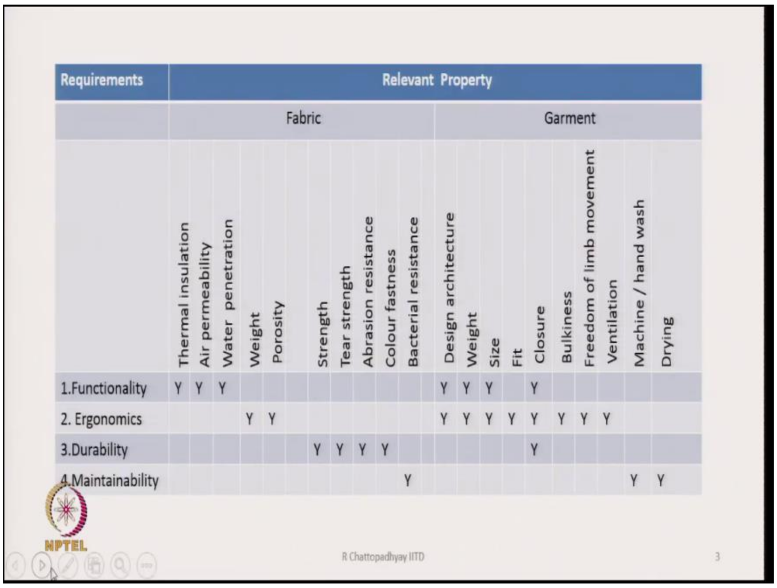

| Requirements | Relevant Property | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fabric | | | | | | | | | | | Garment | | | | | | | | | |
| | Thermal insulation | Air permeability | Water penetration | Weight | Porosity | Strength | Tear strength | Abrasion resistance | Colour fastness | Bacterial resistance | Design architecture | Weight | Size | Fit | Closure | Bulkiness | Freedom of limb movement | Ventilation | Machine / hand wash | Drying |
| 1.Functionality | Y | Y | Y | | | | | | | | Y | Y | Y | | Y | | | | | |
| 2. Ergonomics | | | | Y | Y | | | | | | Y | Y | Y | Y | Y | Y | Y | Y | | |
| 3.Durability | | | | | | Y | Y | Y | Y | | | | | | Y | | | | | |
| 4.Maintainability | | | | | | | | | | Y | | | | | | | | | Y | Y |

Here, the table illustrates the properties of the fabric and the properties of the garments in the columns, and the requirements are mentioned in the first column. There are four important requirements. They are functionality, ergonomics, durability, and maintainability. To better understand how these requirements are met, identification of the relevant properties of the fabric and garments is necessary. When considering fabric functionality, the thermal insulation of the fabrics we intend to use is important.

Following that, air permeability and water penetration are also important aspects related to the fabric. Additionally, factors concerning the garments, such as their design architecture and overall design concept, play a significant role in functionality. Other considerations include the weight and size of the garment. Next, designing various closure systems is an important aspect from a functionality point of view. From an ergonomic perspective, the weight of both the fabric and the garment is important, along with fabric porosity. If the structure is too porous, it may lead to a rapid loss of warmth, making the wearer feel cold more quickly.

From an ergonomic point of view, key factors include the design architecture, weight, size, fit, closure systems, and the bulkiness of the garment. Then, freedom of limb movement, which is the ability to move limbs freely and the presence of proper ventilation for comfort are also important considerations. These aspects are important considerations for ergonomics. Ergonomics focuses on the mobility of various limbs, particularly the hands and legs, as the person needs to perform tasks involving turning, twisting, and sometimes crouching, depending on the nature of the work.

When considering durability, the relevant properties of the fabric or garment are strength, tear resistance, and abrasion resistance. Strength primarily refers to tensile strength, along with factors like colour fastness and the types of closures used, as there are various closure systems available nowadays. All these elements have an influence on the durability and maintainability of the garment or clothing.

The properties mentioned in the table are not complete in all aspects, and additional factors should always be considered. The key is understanding which fabric and garment properties are important for functionality, ergonomics, and durability considerations. This ensures that all relevant factors must be considered when producing clothing that meets customer requirements.

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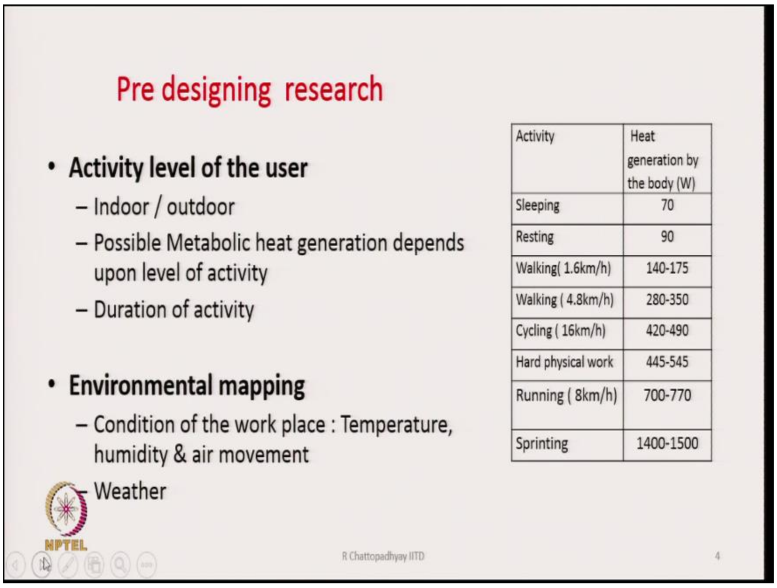


The need to do some pre-designing research is essential in such situations. This involves understanding the level of activity of the user and determining whether the garment will be used indoors or outdoors, as these environments require different design approaches. In the indoor environment, strong winds, snow, or rain are not expected. Whereas in an outdoor environment, these factors must be considered.

Next is the consideration of metabolic heat generation, which also depends upon the activity of the person. All humans continuously produce heat, known as metabolic heat, and the amount of heat generation depends on the level of activity. Additionally, the duration of the activity is also included, whether it is half an hour, one hour, or two hours of continuous work, which affects the design requirements for the garment.

It all depends on the profession, and on the right-hand side, there's a table that provides an overview of different types of activities and the corresponding heat generated. Even during sleep, the human body produces about 70 watts of heat. While resting, it is around 90 watts. Slow walking generates 140 - 175 watts, and brisk walking at 4.8 km/h can generate between 280 - 350 watts of heat.

For cycling, values range from 420 to 490 watts, depending on the individual. Hard physical activity generates between 445 to 545 watts, whereas running generates 700 to 770 watts. Sprinting can produce 1400 to 1500 watts. This shows that heat generation is directly linked to the intensity of the activity. Additionally, consideration of the environment in which the person will stay is required. Therefore, it is essential to understand the conditions of the workplace, especially if the garment will be used during work. These factors include weather conditions such as temperature, humidity, and air movement.

Additionally, the general weather patterns must be considered, as the garment may be required for specific periods ranging from two months to six months, depending on the duration of winter. In some countries, winter lasts throughout the year, while in others, it may last for six, four, or just two months. Therefore, depending on the target market, products designed for the Indian market may not be suitable for the European market due to the significant differences in weather conditions.

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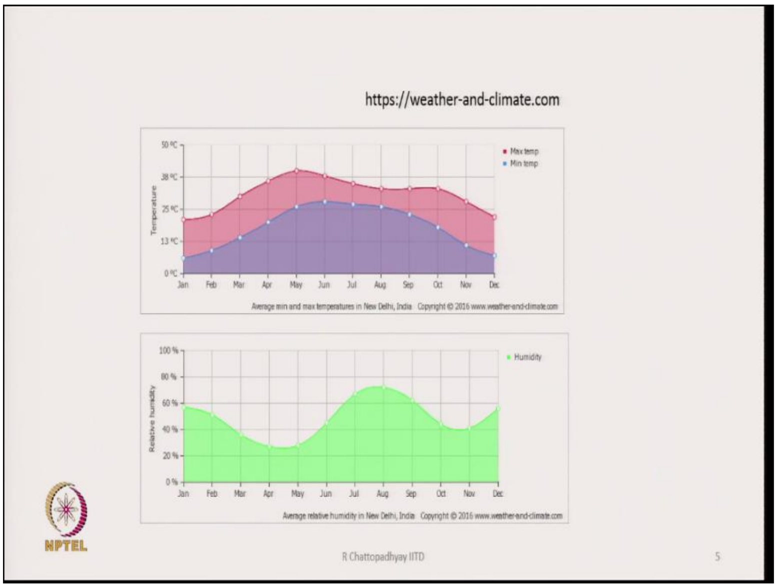


The data related to climate conditions has to be gathered. For example, we can examine how temperatures in New Delhi, India, vary from January to December, including both minimum and maximum temperatures. This gives a clear understanding of temperature changes throughout the year.

For any products that are produced, depending upon the usage of the persons, the proper designs have to be made. Additionally, humidity must be considered, which is illustrated in the graph below.

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Next, the number of sunshine hours and whether there will be precipitation, such as rain or snow, must be considered. The data on rain or snow needs to be collected in cases where the garment plays an important role in the survival of the person who is using it. All these factors need to be considered, and some aspects may be less important and can be ignored.

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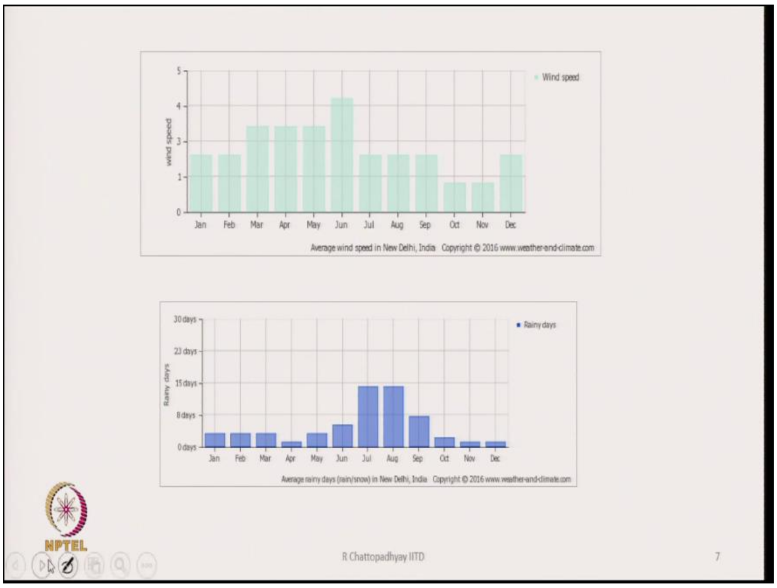


Additionally, wind speed data is provided throughout the year, along with the number of rainy days. All this information is valuable and helps us understand climate conditions. We must gather and consult relevant climatic data for design decisions.

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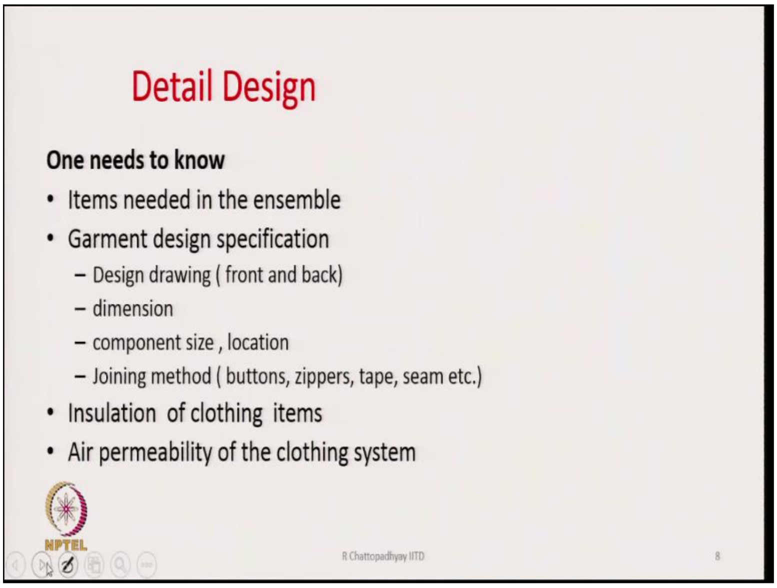


Next comes the detailed design process. It is important to identify the custom items needed for the ensemble, as a person typically wears more than just a single jacket. Hence, the different items of the ensemble must be known. Next, the garment design specifications have to be developed, which include design drawings that illustrate how the garment will look and the number of parts it will consist of. It must also specify where the seams should be placed and what types of seams to use; this level of detail is essential.

The design drawings help as communication tools, enabling the designer to convey the message to the production team. This communication must be such that the production team should be able to accurately understand the designer's thoughts. From the communication point of view, it is important to include diagrams because they provide a quick and clear method to convey information, reducing ambiguity compared to text material.

Next are the various dimensions of the various parts of the garment, including their sizes and locations. This information is important for understanding where each component should be positioned within the design. The joining methods, whether they are buttons, zippers, tape, or seams, must be worked out to develop the design specifications. These specifications are passed on to the production team, who will manufacture the garment. The insulation value of each clothing item that will be used has some role in the overall insulation of the ensemble.

Air permeability of the entire clothing system is another important factor. It is not the single fabric that is included; the ensemble consists of layers of fabric. Hence, it is essential to know the air permeability of the clothing system. Additionally, moisture vapour transmission is another important aspect, whether moisture can easily pass through or is restricted because it will have an influence on the comfort aspect of the winter garment. All these factors must be considered during the detailed design process.

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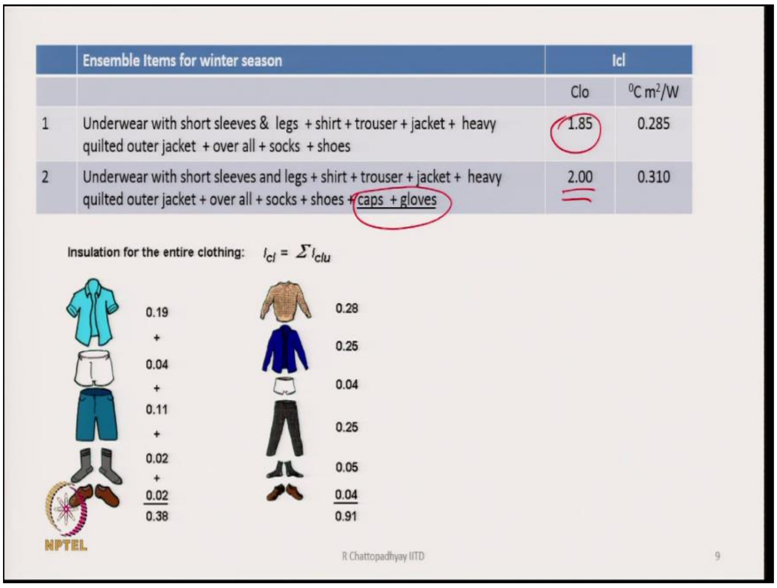


In this diagram or table, an example of a typical winter ensemble is provided. For example, ensemble 1 included items such as underwear with shorts sleeves and legs, a shirt, trousers, a jacket, a heavy quilted outer jacket, overalls, socks, and shoes, which gives a total Clo value of 1.85. Each item in the ensemble has its own Clo value, and there is a standard which is available.

The Clo value of individual clothing items is added to determine the total Clo value of an ensemble. For example, in Ensemble 2, which includes an undershirt with short sleeves and legs, a shirt, trousers, a jacket, a heavy quilted outer jacket, overalls, socks, and shoes, along with two additional items such as caps and gloves, which give a total Clo value of 2. Both the cap and gloves contribute insulation value, helping to keep the wearer warm.

Therefore, the ensemble 2 has a Clo value higher than the ensemble 1. The only difference is the addition of gloves and a cap, which increases the Clo value by 0.15. As shown in the example, by adding the Clo values of individual items, the total Clo value for the entire ensemble can be calculated.

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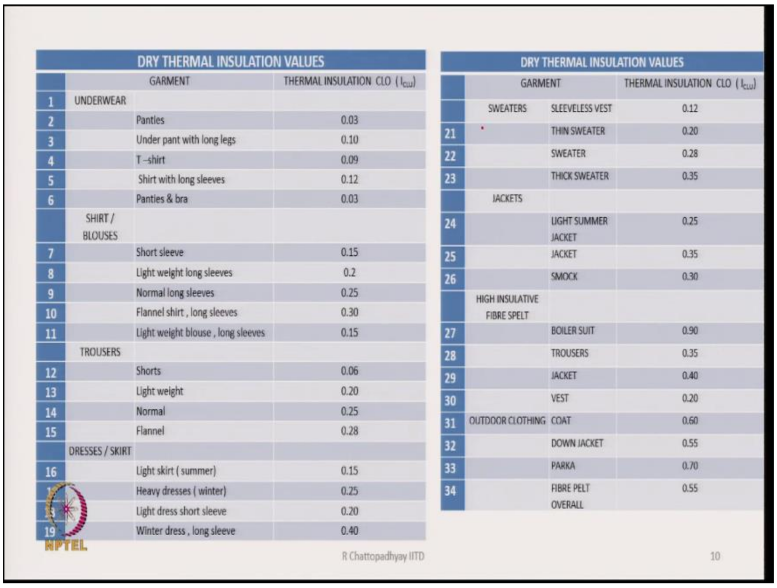

DRY THERMAL INSULATION VALUES

| | GARMENT | | THERMAL INSULATION CLO ($I_{clu}$) |
|---|---|---|---|
| 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 | 0.2 |
| 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 |
| [illegible] | | Heavy dresses ( winter) | 0.25 |
| [illegible] | | Light dress short sleeve | 0.20 |
| 19 | | Winter dress , long sleeve | 0.40 |

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 |
| | JACKETS | | |
| 24 | | LIGHT SUMMER JACKET | 0.25 |
| 25 | | JACKET | 0.35 |
| 26 | | SMOCK | 0.30 |
| | HIGH INSULATIVE FIBRE SPELT | | |
| 27 | | 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 |

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This is a simple method to determine Clo values. As I mentioned, there is an available standard provided by Ashrae. These standards offer typical Clo values for various types of garment items, such as different kinds of underwear, shirts, and blouses, along with their corresponding Clo values. Many of these items have been tested on mannequins, and standardized values have been established. These can be referred to when developing an ensemble that suits the specific requirements of an individual. There are numerous items listed, including sweaters, jackets, high-insulating fibre garments, and outdoor clothing such as coats and down jackets. Each of these items has corresponding Clo values provided in the list.

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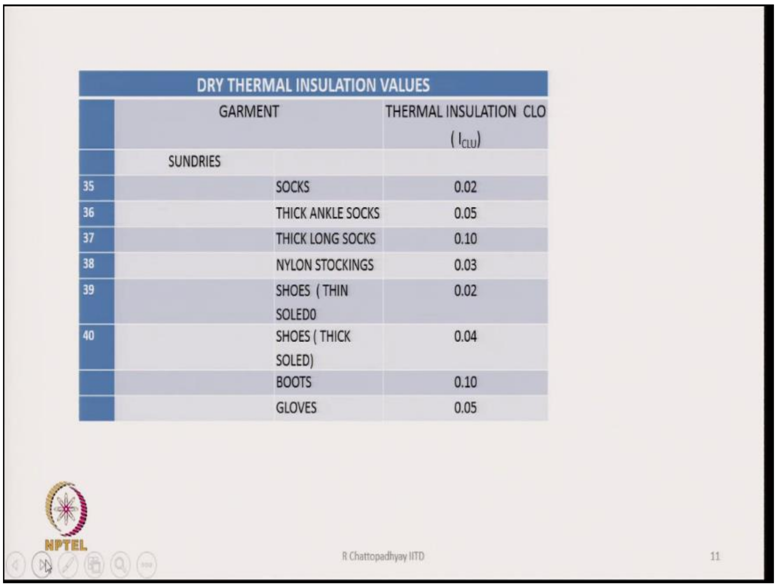

DRY THERMAL INSULATION VALUES

| | GARMENT | | THERMAL INSULATION CLO ($I_{clu}$) |
|---|---|---|---|
| | SUNDRIES | | |
| 35 | | SOCKS | 0.02 |
| 36 | | THICK ANKLE SOCKS | 0.05 |
| 37 | | THICK LONG SOCKS | 0.10 |
| 38 | | NYLON STOCKINGS | 0.03 |
| 39 | | SHOES ( THIN SOLED0 | 0.02 |
| 40 | | SHOES ( THICK SOLED) | 0.04 |
| | | BOOTS | 0.10 |
| | | GLOVES | 0.05 |

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This list contains up to 40 items, each with corresponding Clo values. By selecting relevant items from the list, collecting their Clo values, and summing them up, the total Clo value for an ensemble can be estimated. The key point is determining how much Clo value is needed to keep a person comfortable in a specific situation. Calculating the total Clo value required for comfort in a given environment is a separate consideration, and it also needs to be worked out.

If the required insulation values are known, whether it is 1.8, 2 or 4, the appropriate items can be selected to ensure that the entire body is covered. By using these values, the total Clo value of the ensemble can be calculated. With this approach, it becomes possible to determine if the selected items will meet the desired insulation level.

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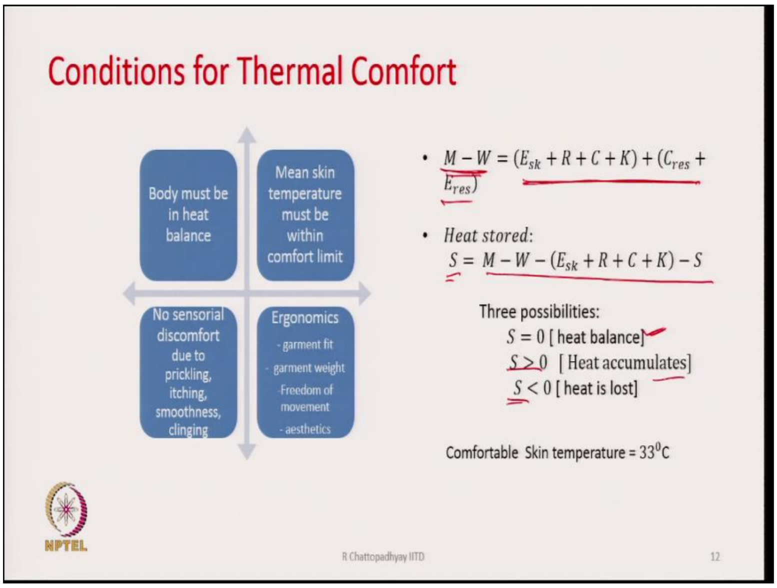


The other thing that is of condition for thermal comfort is that the body must be in heat balance. The mean skin temperature must be within a comfort limit. There should be no sensorial discomfort caused by prickling, itching, smoothness, or clinging from the garment. From an ergonomic standpoint, garment fit, weight, freedom of movement, and aesthetics are important considerations. The basic equation of thermal comfort stated here is '$M - W$', which refers to the difference between metabolic heat production ($M$) and mechanical work done by the body ($W$). The equation for heat storage can be expressed as '$M - W - (E_{sk} + R + C + K) - S$'. Hence, three possibilities are how much metabolic heat is produced and then how much work is being done. So that the heat balance is always maintained. If '$S = 0$', the heat balance is perfect, meaning the metabolic heat produced equals the heat lost through the garment and the environment, and equilibrium will be established, and some heat will always flow out.

The important thing is that the amount of heat generated, minus the work done, should equal the heat released from the body through the garments. When '$S = 0$' or close to it, the heat balance is perfect, and the person feels very comfortable. If '$S > 0$', heat will gradually accumulate over a period of time, leading to an increase in skin temperature. As a result, the person will begin to sweat and experience discomfort. The discomfort will not occur immediately. The body can tolerate slight deviations where '$S$' is slightly above or below 0. Hence, there is a tolerance within which the body will still feel comfortable. But, if these threshold values are exceeded, heat will accumulate over time, leading to an increase in skin temperature and resulting in discomfort. Consequently, the person may begin to sweat.

Sweating causes additional problems for designers because of the liquid which is there on the skin. Most sweat consists of water, which is a good conductor of heat. When sweat either remains on the skin or penetrates through the fabric layer closest to the skin, the thermal insulation value decreases significantly. As a result, heat loss occurs more rapidly. This is one of the important aspects of the design of winter clothing. Is '$S < 0$', This means excessive heat loss occurs, and the person will start feeling discomfort as the skin temperature drops below a comfortable level. This will lead to a different kind of sensation, resulting in shivering after some time, which also needs to be prevented. Therefore, maintaining the right balance is important.

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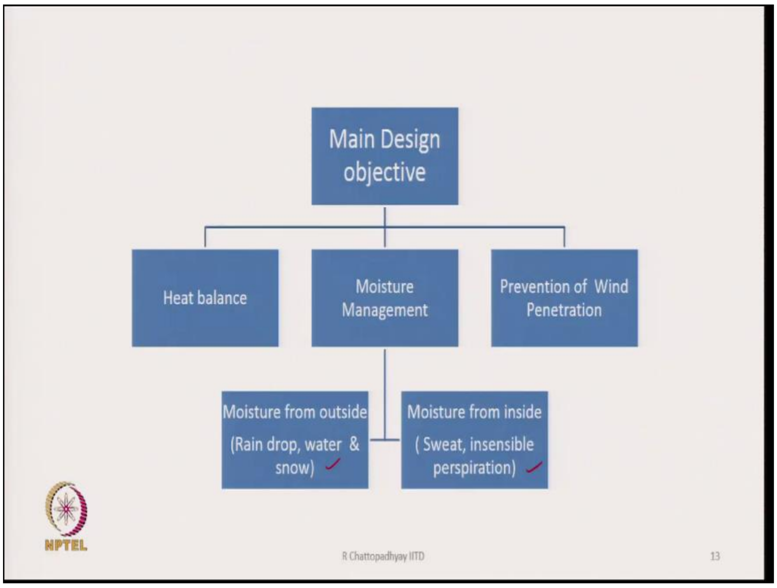

Therefore, the main design objectives are heat balance and moisture management, as the body continuously generates moisture. This moisture is subtle and often goes unnoticed or insensible until it gets converted into sweat. We cannot realize this moisture, but the body continuously generates some amount of moisture. This moisture moves out of the body and mixes with the surrounding air.

Moisture management is important. It involves preventing external moisture, such as rain, water splashes, or snow, from penetrating and sensible perspirations such as sweat must also be managed. Moisture management has two key aspects, i.e., preventing liquid entry from the outside (whether from raindrops, water splashes, or crossing through snow or a river), and effectively handling the moisture generated inside the clothing (sweat or insensible perspiration).

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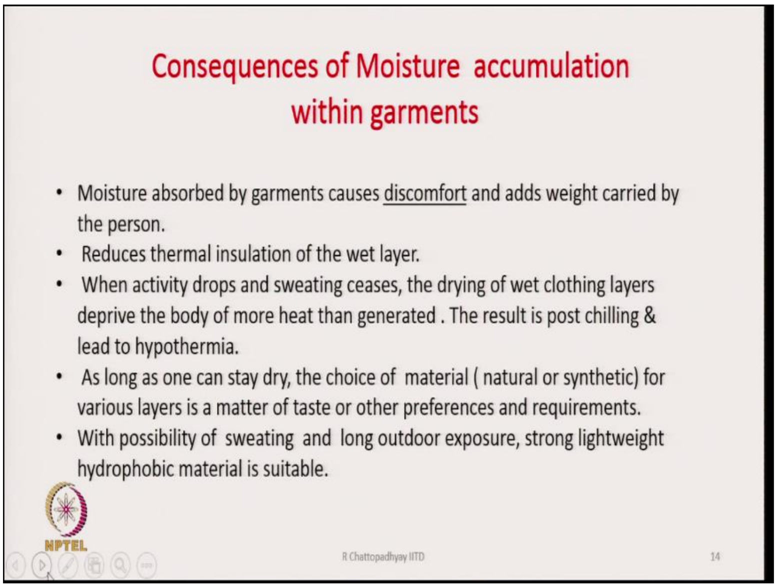


The accumulation of moisture in garments leads to discomfort and adds to the weight carried by the person. It also reduces the thermal insulation of the clothing layers. When physical activity decreases and sweating stops, the wet garments begin to dry, which draws more heat from the body than it generates because the body will be trying to lose the heat faster because the layers are wet as the water is there. This can result in post-chilling and, in severe cases, lead to hypothermia.

Therefore, proper moisture management is essential for individuals working while wearing these garments. As long as one stays dry, the choice of material, whether natural or synthetic, for the various layers becomes a matter of other preferences, comfort, or specific requirements. Another consideration could be the desire for a lightweight garment, which would require the use of low-density fibres.

In this case, we would look for fibres with lower density, such as polypropylene, acrylic, or polyester, all of which are known for their lightweight properties. These low-density fibres are suitable because weight plays an important role. Another key requirement could be the need for quick drying or the moisture or the water to be released first, especially when the garment becomes fully wet.

In such cases, the moisture or water should be easily removed. We can squeeze out most of the water, allowing the garment to dry more quickly. So that the garment can dry within an hour or two. In the meantime, we can do other activities or even wrap the garment around our body to stay warm. Such kind of unexpected situations may arise.

Therefore, quick drying also could be a very important requirement in certain situations, especially for those trekking or working in the hills, which could be an important consideration for them. With the possibility of sweating and long outdoor exposures, strong, lightweight, hydrophobic material is suitable. In such conditions of outdoor exposure, hydrophobic fibres like polyester, acrylic, or polypropylene would be well-suited.

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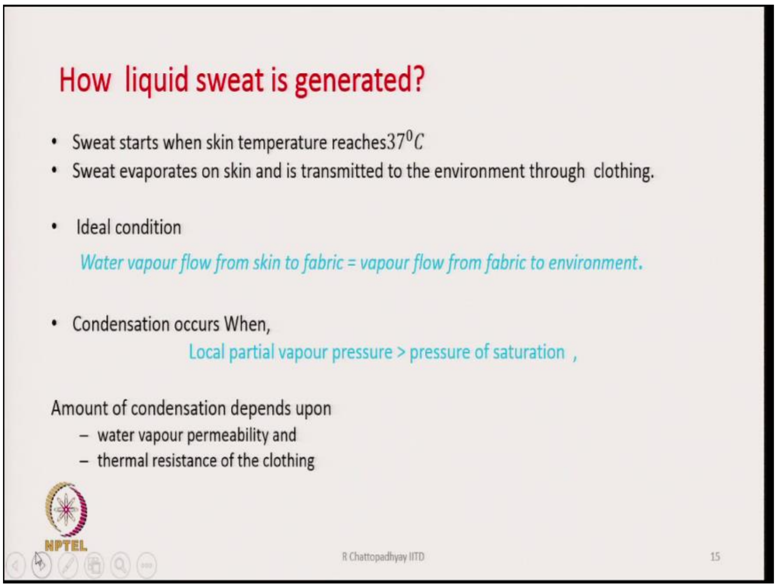

It is necessary to understand how liquid sweat is generated. Sweat starts when skin temperature reaches 37˚C and sweat evaporates on the skin and is transmitted to the environment through clothing. Hence, the ideal condition is for water vapour to flow from the skin to the fabric and then from the fabric to the environment. In this balanced condition, water vapour leaving the skin should equal the amount escaping from the fabric to the environment.

Generally, this ideal situation does not happen. Condensation of moisture can take place when moisture from the skin transfers to the garment layers. Irrespective of the layers present, moisture can accumulate within them. When the local partial vapour pressure exceeds the saturation pressure, condensation occurs. That is, the moisture will be converted into liquid form; this possibility could be there.

The amount of condensation that occurs depends on the water vapour permeability and thermal resistance of the clothing. If the water vapour permeability is high, condensation will be less; however, the thermal resistance of the clothing also plays an important role. Designers must consider the possibility of condensation in certain situations and ensure that the clothing can protect the wearer under such conditions.

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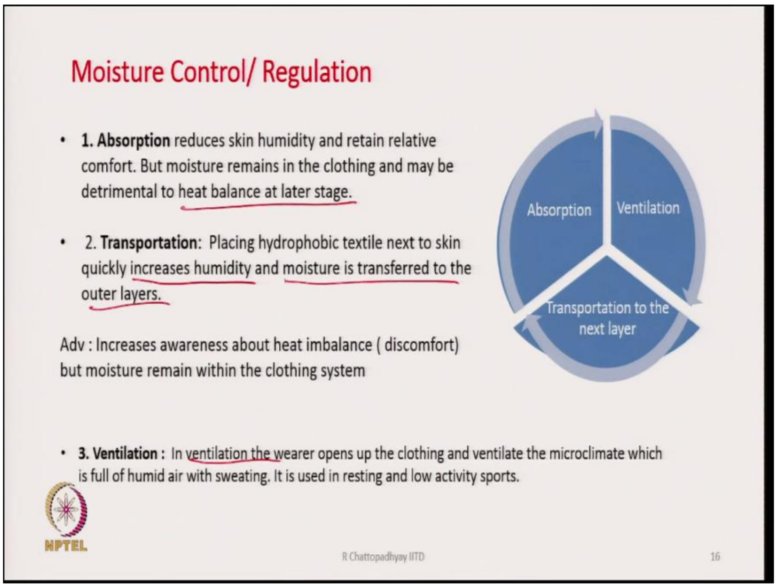


Let us discuss how moisture can be controlled or regulated. There are three important mechanisms for moisture control. They are absorption, ventilation, and transportation to the next layer. Absorption reduces skin humidity and retains relative comfort. However, the moisture absorbed from the skin remains in the clothing and may be detrimental to heat balance at a later stage.

If we have a layer of fabric next to our skin that effectively absorbs moisture, any moisture generated will be quickly absorbed by this fabric. This means the skin will remain dry, creating a favourable situation. Therefore, it is beneficial to use a material that can effectively absorb moisture to enhance comfort. It is essential to select fibres that can quickly absorb moisture, but this absorption may become detrimental to heat balance if the moisture is not released quickly enough.

If the absorbed moisture accumulates and eventually condenses into water, insulation value will decrease, leading to discomfort. Initially, this moisture absorption can be beneficial for a short period of time, but when a person must wear it for a long period of time, then it may be detrimental because it will hold the moisture, which may get transformed into a liquid and eventually the fabric will reach a saturation level after some time.

Once this occurs, insulation values drop significantly, causing the fabric to cling to the skin and resulting in discomfort. Another consideration is the transportation of moisture. Placing hydrophobic textiles next to the skin quickly increases humidity, and moisture is transferred to the outer layer. While it may seem beneficial to use hydrophobic material near the skin, the negative point is that these materials do not absorb moisture.

As a result, moisture can accumulate between the fabric and the skin, and that microclimate will get saturated with moisture very fast. The person will start feeling discomfort because the rate at which moisture is generated does not match the rate at which it crosses the fabric barrier. Consequently, moisture accumulates between the fabric and the skin, leading to rapid discomfort.

However, the advantage of using hydrophobic materials is that they facilitate the transfer of moisture to the outer layer because they will not hold the moisture. It can effectively allow moisture to the next layer, provided that the next layer absorbs the moisture. It is important to carefully select the fibres that need to be used next to the skin. Another method for moisture control is ventilation, which plays an important role in garment design.

The garment design must incorporate a ventilation feature to allow the wearer to open the clothing and release the humid air and sweat. This is particularly used during resting and low-activity sports. The garment has to be designed in such a way that it has many vents and cuts to facilitate the removal of saturated, moist air next to the skin, and the person may feel comfortable because the accumulation of moisture next to the skin is a source of discomfort.

Hence, ventilation should be present in garment design for uniforms. Now, the question arises regarding where to place the ventilations and how much ventilation is necessary. Ventilation requires openings, but these openings must be such that they should not allow the air to come in, as well as to keep rain from getting inside the uniform or garment. Hence, these aspects must also be considered while designing the ventilations.

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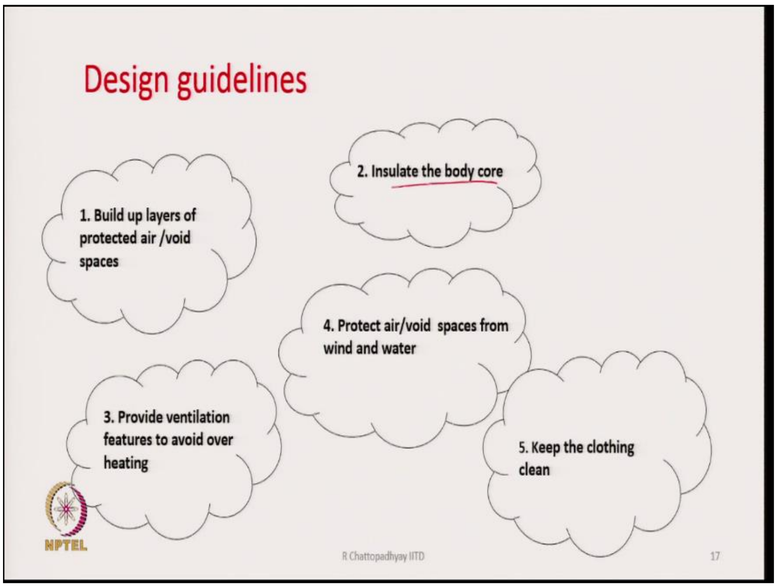


The important points for the design guidelines are to build up layers of protected air and void spaces because of the need for more insulation, and insulation mainly comes from void spaces. This is important from the point of view of insulations: insulate the body core, provide ventilation features to avoid overheating, protect air or void spaces from wind and water, and keep the clothing clean.

All of them should be important as a part of design guidelines. Building upon layers should be such that whatever voids are there; voids should not be such that the air can easily enter. Otherwise, the cold air from outside may easily enter and penetrate the garment. This could lead to rapid heat loss from the garment. A void is required, but it needs to be protected from air or rainwater entry to maintain warmth and insulation.

The core part of the body needs more insulation, and hence, insulating the body core is essential. Another important aspect is to identify which parts of the body lose the most heat. The areas where maximum heat loss occurs must first be taken care of with suitable insulations because they hold vital organs. Hence, more insulation must be provided to these areas than other parts of the body.

The insulation required for the trunk part of the body, where vital organs like the heart and lungs are located, differs from that needed for legs or hands. The level of protection and insulation for the trunk should be greater than that for the limbs, and the insulation needed for different body parts will not be the same. Different parts of the body require varying levels of insulation, which is an important consideration.

There are many other aspects also present. Ventilation features should be provided in the design, protecting air and voiding places from wind and water. Further, keeping clothing clean is important; dirt and contaminants can significantly reduce its insulation value.

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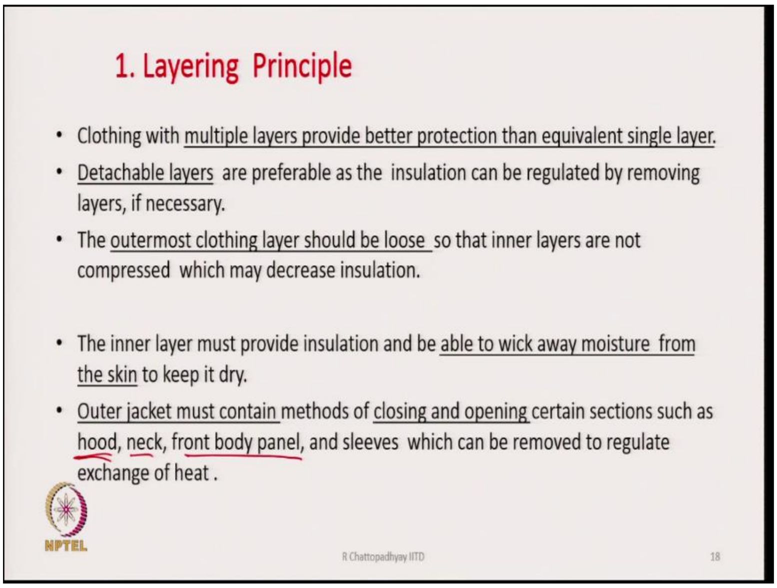


In the layering principle, clothing constructed with multiple layers provides better thermal protection than an equivalent single layer because, between layers, there will be a layer of air, which further enhances the insulation. Hence, multiple layers are more effective than a thick single-layer garment. Detachable layers are preferable as the insulation can be regulated by removing layers if necessary. This is another way to reduce the insulation value if it is required.

The outermost clothing layer should be loose so that the inner layers are not compressed, which may decrease insulation. It is essential that the outer layer is larger in size to avoid compressing the inner layers. Compression reduces thickness, and a reduction in thickness leads to a decrease in insulation value. The inner layer must provide insulation and be able to wick away moisture from the skin to keep it dry. This is important; otherwise, moisture accumulation causes a reduction in insulation value.

The outer jacket must have mechanisms for closing and opening certain sections, such as the hood, neck, front body panel and sleeves. These features allow for the regulation of heat exchange. Incorporating features like a hood in the neck and removable front body panels, which allows the removal of some parts of the garment whenever required. This helps to regulate the loss of heat from the body and maintains heat balance, which enhances comfort.

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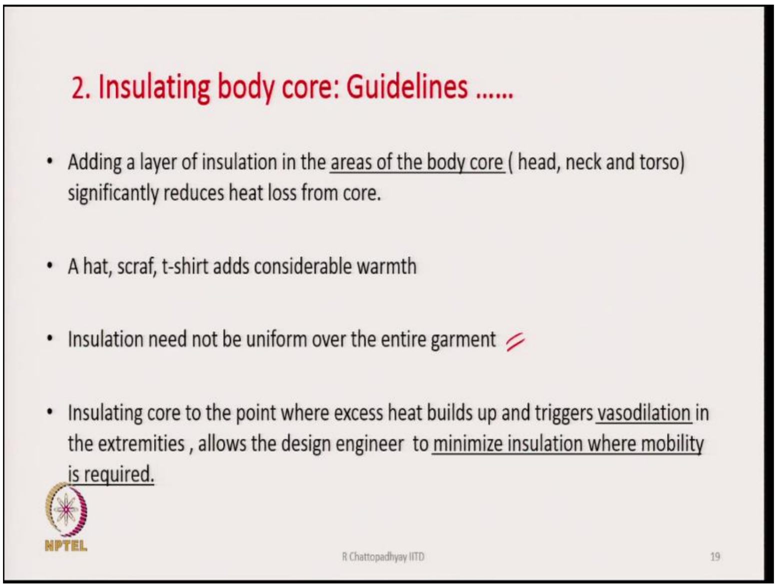


Insulating the body's core, particularly the trunk area where vital organs such as the heart and lungs are located, has to be insulated, and we have to be careful about this part of the body. The important thing is adding a layer of insulation in the areas of the body's core, such as the head, neck, and torso, significantly reduces heat loss from the core. This is the research findings. It is important to consider that a hat or scarf can add considerable warmth.

A considerable amount of heat is lost from the head, and therefore, wearing a hat or cap can provide substantial insulation and keep the body warm. Additionally, insulation does not need to be uniform across the entire garment. Different parts of the body have varying insulation requirements, so the garment should be designed accordingly to address these specific needs.

Insulating the core to the point where excess heat builds up can trigger vasodilation in the extremities. This response allows the designer or design engineer to minimize insulation in areas where mobility is required. This is helpful because if the insulation requirement near the hand is less, then a thinner fabric or a thinner ensemble facilitates the easier movement of limbs.

Otherwise, restricting mobility and movement will be difficult if a thicker layer is used in the torso, arms and legs. The parts which are away from the heart require relatively less insulation. So, the fabric or layers of fabric required for those regions are thinner than the fabric required near the torso, and this will help in terms of the mobility of these limbs.

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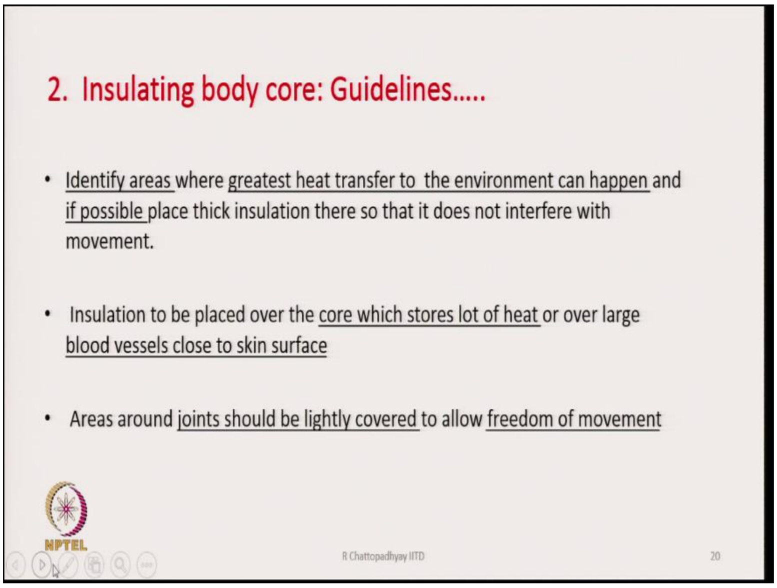


Another important thing is to identify areas where the greatest heat transfer to the environment can happen, and if possible, place thick insulation there so that it does not interfere with the movement. This means that in the torso, as vital organs are present, there will be maximum heat loss. Since the torso remains relatively stationary compared to the limbs, thick insulation can be applied. Hence, there is no difficulty in having a thick layer of material there.

Insulation is to be placed over the core, which stores heat or over large blood vessels close to the skin's surface. Areas around joints such as knees, elbows and wrists should be lightly covered to allow freedom of movement. In areas with joints, it is important to ensure that the joints can move easily. Therefore, the placement of fabric or the layers of the fabric used in these regions should be slightly thinner to allow freedom of movement.

For example, in any jackets used by the army or navy, it can be noticed that the designs are such that the placement of material or the thickness of the jacket is not the same everywhere.

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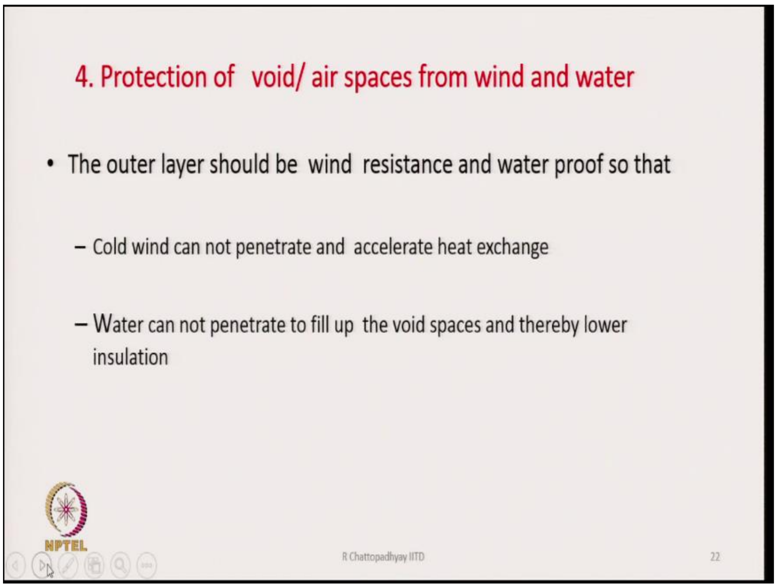


Ventilation features are important for regulating overheating, which sometimes can occur due to intense physical activity or high insulation values that can lead to overheating of the body and the skin. Structural elements like collars, cuffs, and belts can be designed to allow ventilation when loosened, enabling air to escape and help cool the body. Netted pockets and vents around the trunk, under the armpits, and along the sides can be used to help release excess body heat through conduction, convection, and radiation by providing access to the skin surface or inner layers of clothing.

To regulate heat, if a person starts feeling warm, the head should be partially uncovered. For example, if wearing a hood, it should be removed; if wearing a cap, the cap can be taken off first to help the body cool down and prevent discomfort. The head should be partially uncovered first, followed by the neck area, upper front, or back to effectively regulate body heat. Opening these areas allows heat to escape quickly from the body, and the person starts feeling comfortable. If there are additional ventilation points, such as buttons or zippers, they should be opened.

By opening the garment, heated air can escape quickly, and loosening the wrist areas or sleeves can also help ventilate through the pumping action that occurs while walking. There are various ways ventilation can provide comfort. Protection of void or airspaces from wind and water. The outer layer of clothing should be wind-resistant and waterproof to prevent cold wind from penetrating and accelerating heat exchange, and water cannot penetrate to fill up the hot spaces, thereby lowering insulations. So, the outer layer should be windproof and waterproof.

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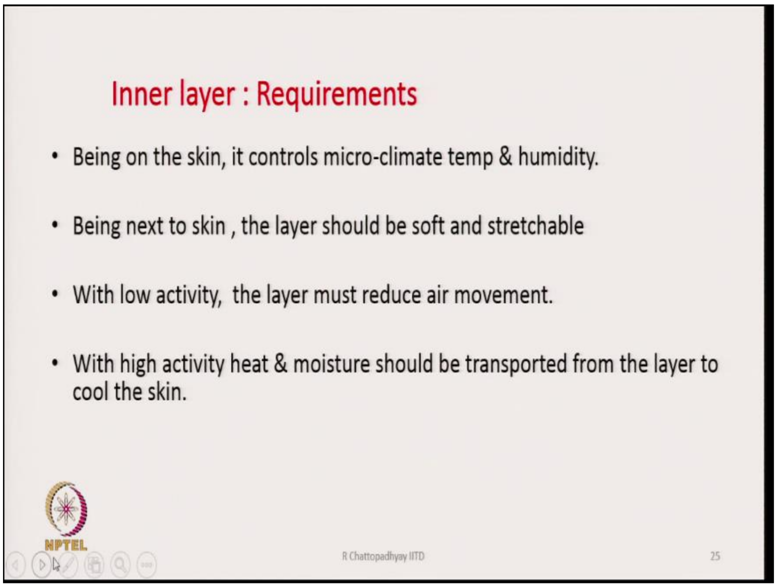


Accordingly, the outer layer must be designed to prevent dirt and maintain insulation. Dirt fills the air pockets within the garment, reducing its insulating ability and promoting bacterial growth, leading to unpleasant odours. Therefore, the garment needs to be cleaned from time to time. When discussing the architecture of winter clothing, it generally consists of three layers: inner, middle, and outer. These layers can be either separable or inseparable from each other.

The inner, middle, and outer layers can either be separable or inseparable, depending on the designer's approach. Both design options are possible and can be chosen based on specific situations. Focusing on the inner layer is important in regulating microclimate temperature and humidity. The layer should be soft and stretchable as it comes into contact with the skin. The prickliness should not be there, and it should be soft in feel.

With low activity, the layer must reduce air movement. It should not allow the air to move; otherwise, convection currents will be generated, and heat loss will be faster. With high activity, heat and moisture should be transported from the layer to cool the skin. As a result, a significant amount of heat and moisture will be generated, and both need to be transported faster to keep this skin cool.

Therefore, the inner layer must possess the ability to transfer both heat and moisture effectively. There are many requirements for the inner layer, which must be soft and stretchable, should be close to the skin, it should be close to the skin and minimize the gap between the first layer and skin; it should also be capable of facilitating the transport of heat and moisture as the activity level increases.

Based on these requirements, design considerations must be made for the inner layer. Fabrics used in this layer should not retain moisture, as moisture retention can increase conductivity. Under all circumstances, the inner layer should be close to the skin and should not hold moisture. This prevents increased conductivity, which could create problems such as reduced thermal insulation.

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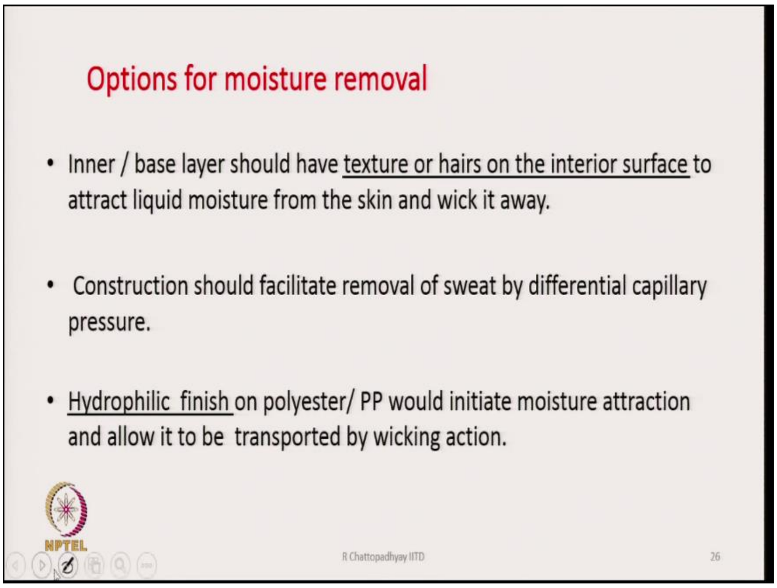


Next is the options available for moisture removal. Moisture accumulation and absorption by the very first layer create a problem. Therefore, the focus must be on the strategies to manage the moisture generated during physical activities. The moisture level generation is not constant;

it depends on the activity level. The other thing is that heat generation will be there, depending on the activity level.

Hence, the same fabric layer must tackle both heat and moisture. Inner base layers should have a textured surface or fibres with fine hairs to protect liquid moisture from the skin, particularly when sweating. This wicking property is important, as it allows moisture to be efficiently moved away from the skin to the next layer. The fabric construction should promote sweat removal through differential capillary pressure, which becomes a key design guideline for transferring moisture from the inner layer to the next layer.

The primary mechanism for moisture removal is capillary pressure. The fabric layers should be designed where capillary pressure will be differential and can be utilized to take out the moisture from the skin to an area away from the skin. A hydrophilic finish on polyester or polypropylene can enhance moisture attraction, allowing it to be transported through wicking action. This approach has been effective, as the hydrophilic finish facilitates moisture movement from the skin to the outer layers.

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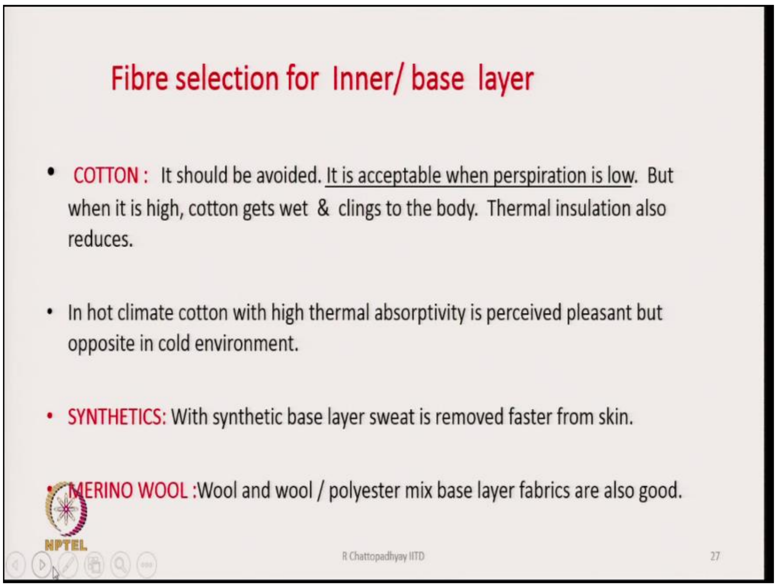


Next is the selection of fibres for the inner or base layer. Some guidelines and issues have been discussed, and they must be considered for the fibre selection. cotton may naturally come to mind, but it should generally be avoided for the inner layer, especially when there is significant perspiration. However, if perspiration is low or minimal, cotton can be used as it provides good comfort and breathability.

When perspiration is high, cotton absorbs moisture, clings to the body, and reduces thermal insulation, making it unsuitable for inner layers during higher activity levels. In hot climates, cotton can feel pleasant due to its high thermal absorptivity, but in cold environments, this effect can be problematic, as it will draw heat away from the body.

On the other hand, synthetic fibres offer a significant advantage for the inner layer during high activity levels as it removes sweat faster from the skin. Because the synthetic fibres do not absorb moisture into the fibres. Instead, the pores and capillaries, which are present between the fibres, take out the sweat from the skin and will be transported to the next layer. Merino wool and wool-polyester blends have also been explored as base layer fabrics and have been found to be quite good, but merino wool is found to be very expensive.

Otherwise, wool, merino wool or wool-polyester blends for the base layer are a good option. Merino wool is fine and soft, and hence, it will not cause prickliness in the skin. On the other hand, coarser wool can cause a prickly sensation and reduce feel and comfort.

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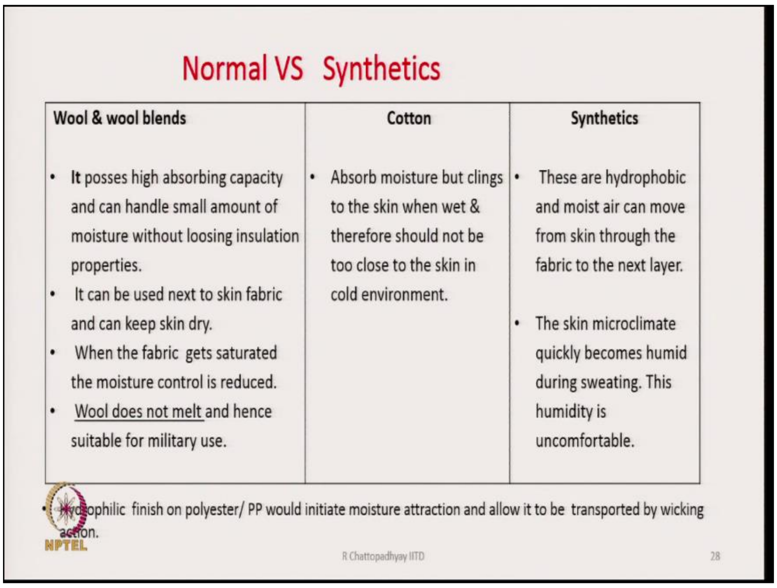


Here, the comparative chart for natural and synthetic fibres, which is used for the inner layer, is represented. Wool, cotton and synthetics are discussed. Cotton absorbs moisture but clings to the skin when wet and, therefore, should not be too close to the skin in a cold environment. Wool and wool blends possess high absorbing capacity and can handle small amounts of moisture without losing insulation properties.

It can be used next to the skin fabric to keep the skin dry. When the fabric gets saturated, the moisture control is reduced. Wool does not melt and is, hence, suitable for military use. A key advantage of wool, especially in military applications, is that it does not melt in high heat or fire situations. Polyester or other synthetic fibre will melt, and the fabric can stick to the skin and cause severe burns to the wearer.

In such a situation, wool performs well as it is known for its self-extinguishing properties. On the other hand, synthetic fibres, being hydrophobic, allow moist air and sweat to move quickly through the fabric to the next layer. However, one negative aspect of synthetics is that during intense sweating, the skin microclimate can become humid more quickly, leading to discomfort.

The microclimate can become humid quickly with synthetic fibres, as these fabrics do not absorb moisture generated by the skin. Hence, moisture accumulates on the surface of the fabric, and once it reaches a saturation point, sweating begins, leading to discomfort. This is the major drawback of synthetics.

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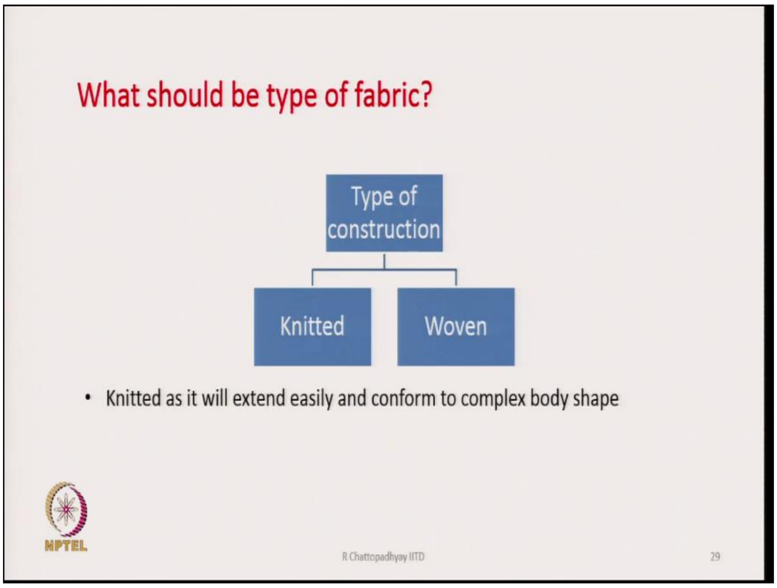


For the inner layer next to the skin, knitted fabrics are generally preferable due to their extensibility and ability to conform to the complex shapes of the body. The stretchability of knitted constructions allows for better movement and comfort than woven fabrics.

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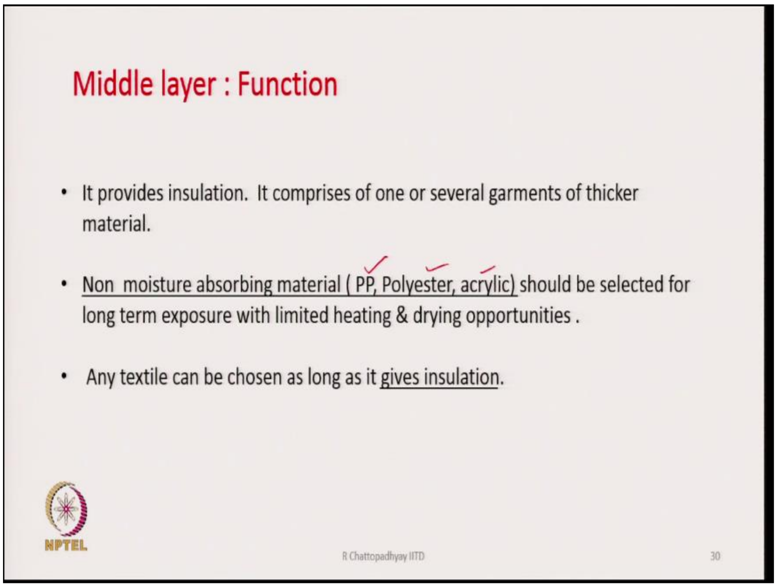


The primary function of the middle layer is to provide insulation. So, it comprises one or several garments of thicker material. Since this layer should not absorb moisture, synthetic fibres like polyester, polypropylene (PP), and acrylic are ideal choices. These fibres are non-absorbent, making them suitable for situations where they are used for the long term without frequent opportunities for heating or drying. Any textile that provides sufficient insulation can be chosen, but the advantage of synthetic fibres is due to their lightweight properties. These fibres have a lower density than cotton. For example, polyester has a density of 1.38 g/cm$^3$, polypropylene around 0.91 g/cm$^3$, and acrylic around 1.14 to 1.18 g/cm$^3$. These fibres have the advantage of being lightweight and voluminous.

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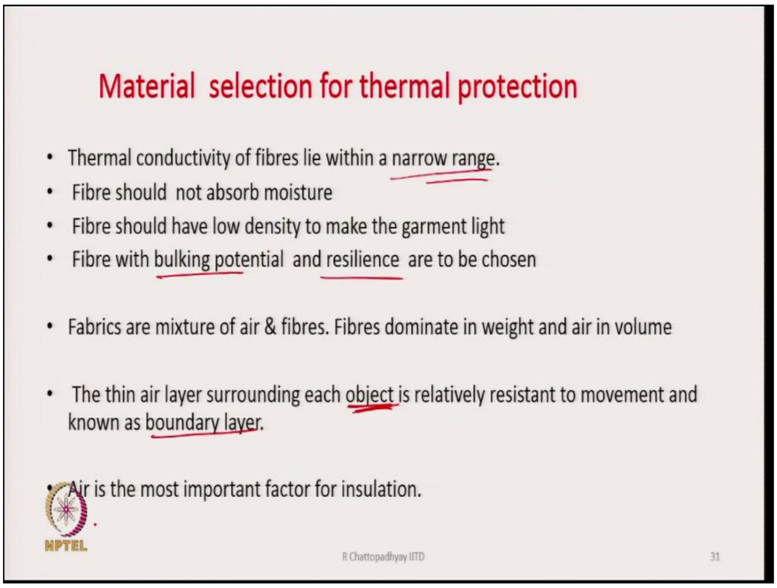

Next comes the selection of materials for thermal protection. The thermal conductivity of the fibre lies within a narrow range. This means that most of the fibres perform similarly in heat transfer. So, from a conductivity point of view, we can say that any fibre can be chosen as it lies in the same range. The other properties also must be taken into consideration that the fibre should not absorb moisture.

Fibers should have a low density to make the garment lightweight. It is also important to select fibres with good bulking potential and resilience. These properties ensure that when the material is compressed and then released, it can effectively retain its thickness. Bulky materials can trap a significant amount of air, which is essential for insulation. The bulking potential and resilience of the fibre are essential factors to consider.

Fabrics are basically a mixture of air and fibre where fibre contributes to the weight, while air occupies most of the volume. The thin air layer surrounding each object is relatively resistant to movement and is known as the boundary layer. This layer of air around each garment plays an important role in insulation.

The thin layers of air present between the inner and middle layers and the missile and outer layers of a garment are known as boundary layers. This layer contributes towards the insulation value of the ensemble. This emphasizes that air is the most important factor for insulation.

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| | Relevant property | Cotton | Polyester | Acrylic | Polypropylene | Wool |
|---|---|---|---|---|---|---|
| 1 | Should not absorb moisture | N | Y | Y | Y | N |
| 2 | water resistant | N | Y | Y | Y | Y |
| 3 | Low density | N | Y | Y | Y | Y |
| 4 | Hollow | N | Y | N | N | Y |
| 5 | Resilient | N | Y | Y | N | Y |
| 6 | Bulky | N | Y | Y | Y | Y |

The properties of typical fibres such as cotton, polyester, acrylic, polypropylene and wool are listed from the point of view of insulations or the point of view of the requirement of the middle layer. The requirement of the middle layer is it should not absorb moisture. This indicates that the cotton is not suitable as it absorbs moisture.

In this table, '$Y$' represents 'yes' and '$N$' represents 'no'. It is observed that for most of the desired properties, cotton is a 'no' for almost everything. Therefore, cotton cannot be used in this particular layer. Other fibres have a chance to be used. Using hollow fibres, polyester, acrylic, polypropylene and wool all are used, but polyester and polypropylene are commonly used because it is cheap.

Using hollow fibres, particularly hollow polyester fibres, is still better and is commercially available. Therefore, these materials can be utilized, as wool has a hollow structure that provides significant warmth; the presence of air in the medulla contributes to this insulation. Similarly, hollow polyester can also be effective. While cotton may not be suitable, other fibres can be selected for this layer.

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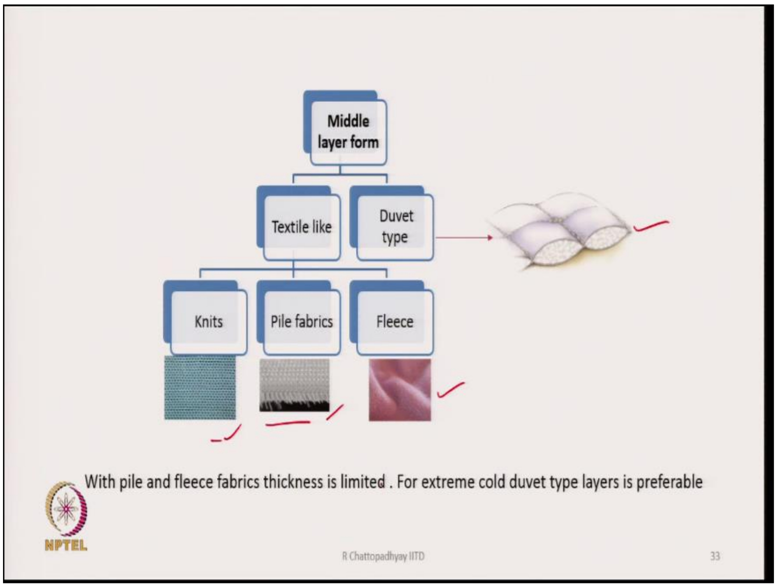


The middle layer could consist of textile materials or a duvet-type design. A duvet type refers to a specific construction style, which could be knitted fabrics, pile fabrics, or fleece. Either of these types can be used, and it is important to determine which one is better for a given situation. Pile and fleece fabrics, known for their thickness, are particularly effective, and for extreme cold conditions, duvet-type layers are the most preferable choice.

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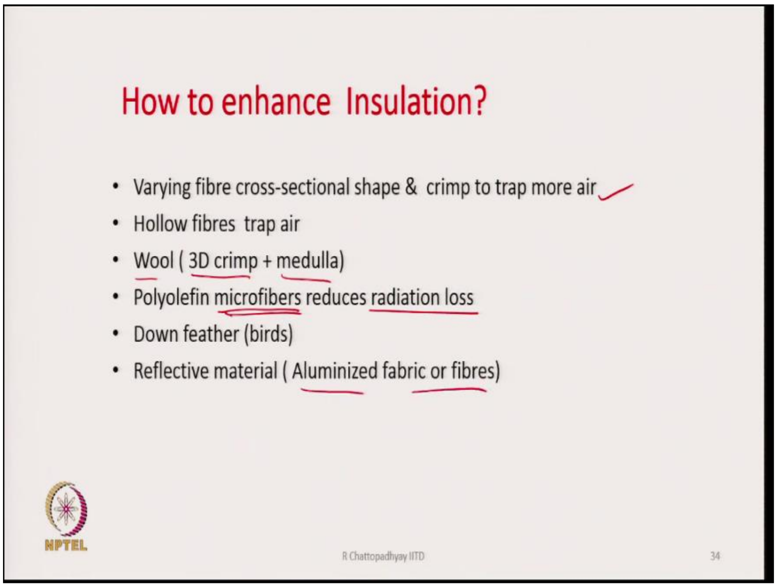


Enhancing insulation is a common question when designing for extreme cold weather clothing. With standard fibres and typical designs, achieving the required level of insulation for cold-weather clothing can sometimes be difficult. One approach is to modify the fibre cross-sectional shape and increase the crimp to trap more air. Instead of using round fibres, non-round fibres or those with more crimp can be utilized to improve insulation. The idea is that creating more pores allows for better air trapping, which enhances insulation.

Hollow fibres can also improve insulation by trapping air within them. Wool provides higher insulation due to its 3D crimp and the medulla. polyolefin microfibers reduce heat loss through radiation, making microfibers effective for minimizing radiation heat loss. Heat loss occurs through three main mechanisms, and radiation is one of the ways where body heat is lost. It is also necessary to consider how to reduce the radiation heat loss. In this case, a highly porous structure is not suitable, and hence, heat loss will be faster beyond a certain porosity.

Reducing porosity can sometimes increase insulation value. Additionally, down feathers from birds can be used for insulation. Reflective materials, such as aluminized fabrics or fibres, are effective in minimizing radiation heat loss from the body. These are some of the key methods to enhance insulation.

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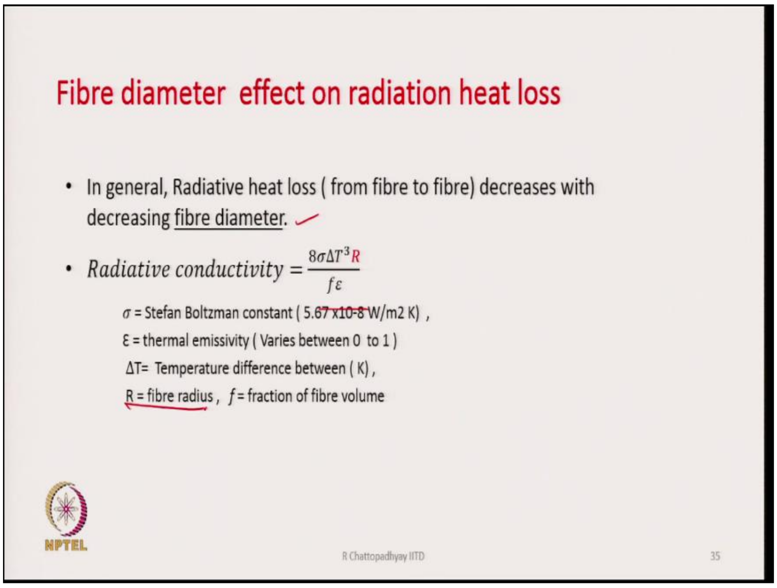


The effect of fibre diameter on radiation loss is an important consideration when selecting fibres for insulation. Questions often arise regarding the appropriate type of fibre, fibre denier or diameter, and cross-sectional shape. These factors are considered during the detailed design process. In general, radiative heat loss decreases with decreasing fibre diameter. According to the formula for radiative conductivity, the fibre radius plays an important role. A larger fibre radius results in higher radiative conductivity.

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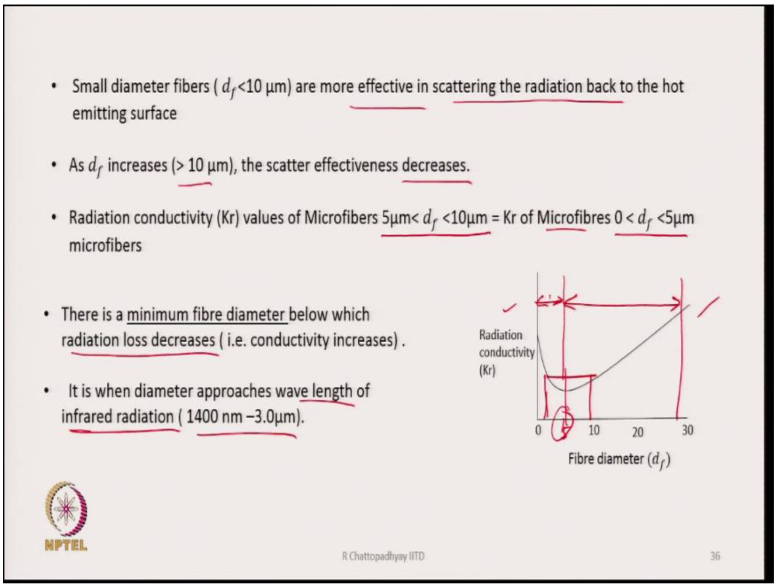


Research has shown a relationship between fibre diameter and radiative conductivity. When plotted, it demonstrates that as the fibre diameter increases within a certain range, the radiative conductivity also increases. This means that larger diameters lead to more heat loss and lower insulation. In the specific range studied, such as around 5 microns, this effect becomes evident. It is observed that as the diameter increases, radiative conductivity decreases in certain zones. This means that the effect of fibre diameter differs between zones.

In one zone with larger diameters, higher conductivity results in less insulation. However, in another zone, as the diameter continues to increase, conductivity decreases, leading to improved insulation. Therefore, the smaller diameter fibres are more effective in scattering the radiation back to the hot emitting surface. As the diameter of the fibre increases, the scattering effectiveness decreases.

The radiative conductivity values of microfibers in the range of 5 to 10 microns are almost equal to the radiation conductivity of microfibers between 0 to 5 microns in this range. Thus, there is a minimum fibre diameter below which radiation loss decreases, typically around 5 or 6 microns. At this diameter, radiative conductivity is at its minimum, resulting in the least heat loss. This phenomenon occurs when the fibre diameter approaches the wavelength of infrared radiation, at which point radiation loss is minimized.

Therefore, fibre diameter significantly affects radiation heat loss. Radiation loss from the human body is a significant component of overall heat loss. While conductive heat loss is present, convective heat loss is relatively negligible. Therefore, it is essential to address radiative loss, where fibre diameter plays an important role. Specifically, there is a fibre diameter that is less than 10 microns. In this specific zone, there is a range of fibre diameters that yield very low conductivity, resulting in less heat loss.

Therefore, it is recommended to choose fibre diameters less than 10 microns, ideally around 5, 6, 7, or 8 microns. While very fine fibres can be difficult to manufacture, selecting fibres in the 5 - 10 micron range will produce a material that effectively minimizes heat loss, especially regarding radiation heat loss. Hence, understanding the effect of fibre diameter is important.

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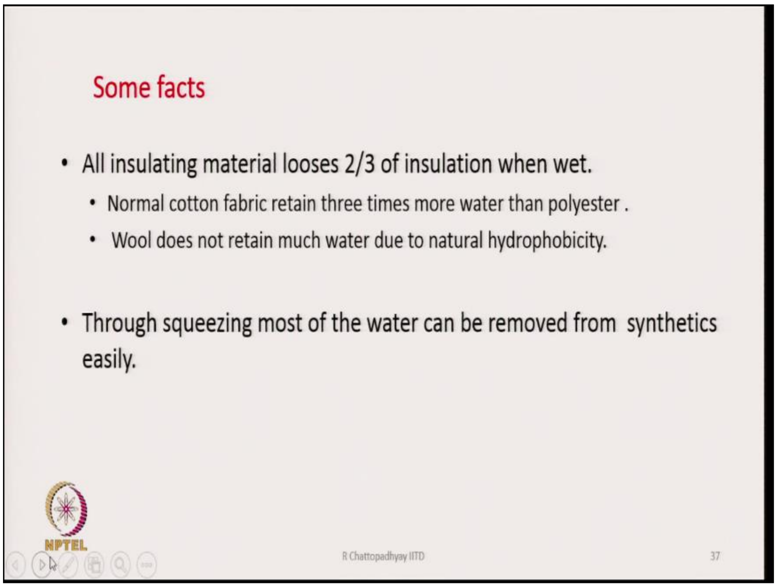


This slide represents some of the important facts to remember. All insulating materials lose two-thirds of their insulation when wet. Normal cotton fabric retains three times more water than polyester. Wool does not retain much water due to natural hydrophobicity. The surface of wool has scales that repel water, causing water to slide off easily when dropped onto it.

However, wool can absorb moisture, with a moisture regain value that is higher than that of cotton. While it does not absorb water droplets, which simply roll off its surface, wool can slowly absorb moisture over time. In contrast, most water can be easily removed from synthetic fabrics through squeezing, a process that is less effective with cotton.

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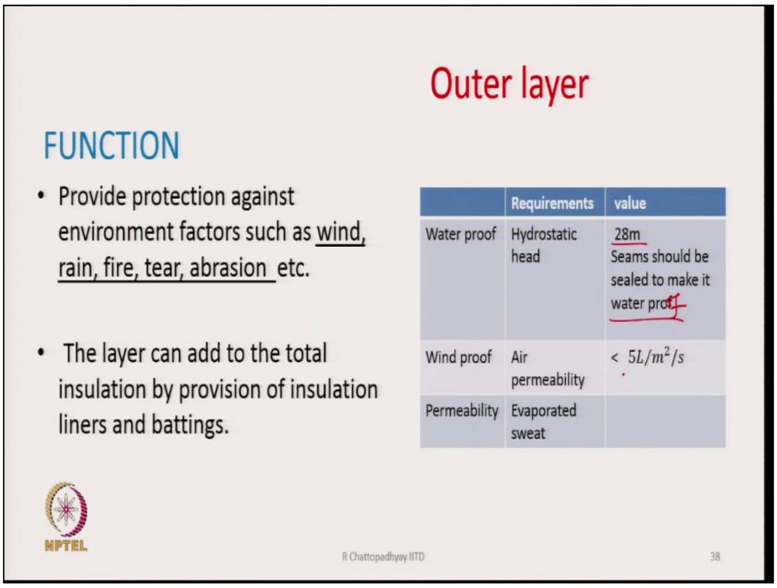

The last component is the outer layer. The function of the outer layer is to provide protection against environmental factors such as wind, rain, fire, tear, abrasion, etc. It is essential to consider these aspects when designing the outer layer. Additionally, this layer can enhance overall insulation by incorporating insulation liners and battings, thereby contributing to the total insulation value of the entire ensemble.

The requirements for the outer layer include waterproofing, with a hydrostatic head of around 28 m. Additionally, seams should be sealed to ensure complete waterproofness. For wind proofing, air permeability must be less than 5 L/m$^2$/s. However, some permeability is necessary to allow evaporated sweat to escape.

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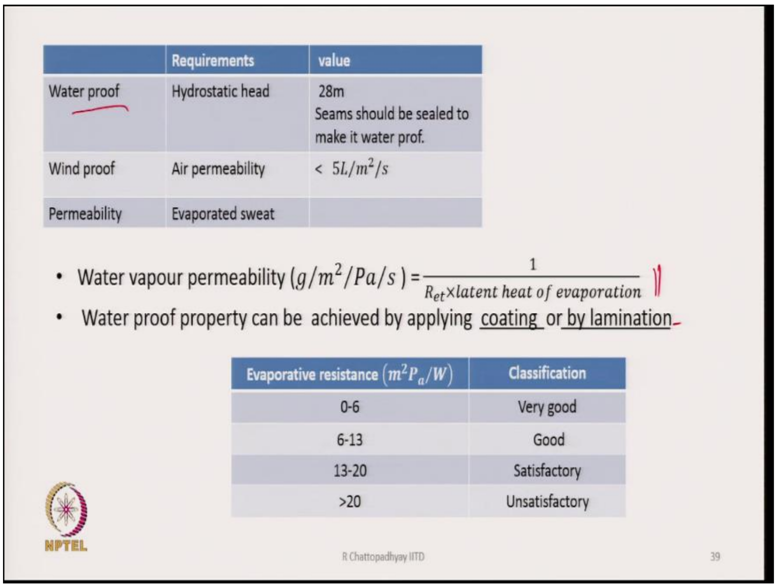


Water vapour permeability can be calculated using the formula

$$\frac{1}{R_{et} \times latent\ heat\ of\ evaporation}$$

Waterproof properties can be achieved through coatings and lamination. To meet the various requirements of the outer layer, waterproofing can be enhanced by applying coatings and laminating materials, as well as by selecting fibres that are hydrophobic in nature.

For example, polyester is hydrophobic in nature. Nylon can also be chosen, which is not as hydrophobic as polyester but absorbs very little moisture. Alternatively, nylon fabric can be used, and a coating or laminate can be applied to enhance its waterproof properties. So that the raindrops cannot penetrate the material, and even if someone crosses a river, the water should not be able to penetrate.

Evaporative resistance values are provided here, along with a classification indicating levels of effectiveness: very good, good, and satisfactory. Evaporative resistance some values are given here and classified as very good, good, and satisfactory. This gives an idea of the different types of resistance that may be present.

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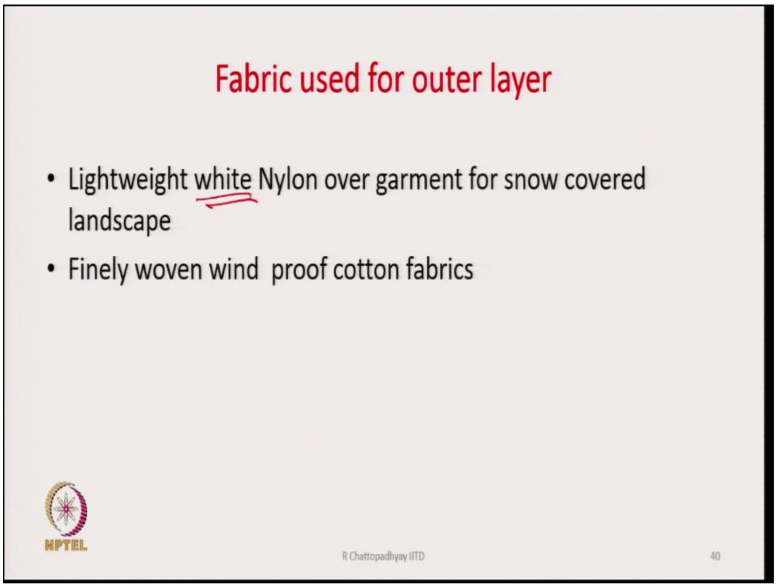


When selecting fabric for outer layers, lightweight white nylon is suitable for environments with snow-covered landscapes, as the colour is important for camouflage. However, this choice can make it challenging to recognize an individual in danger, as their clothing is exactly the same as that of the snow. For effective camouflage, white nylon is necessary, but if visibility from a distance is needed, orange nylon is an excellent alternative.

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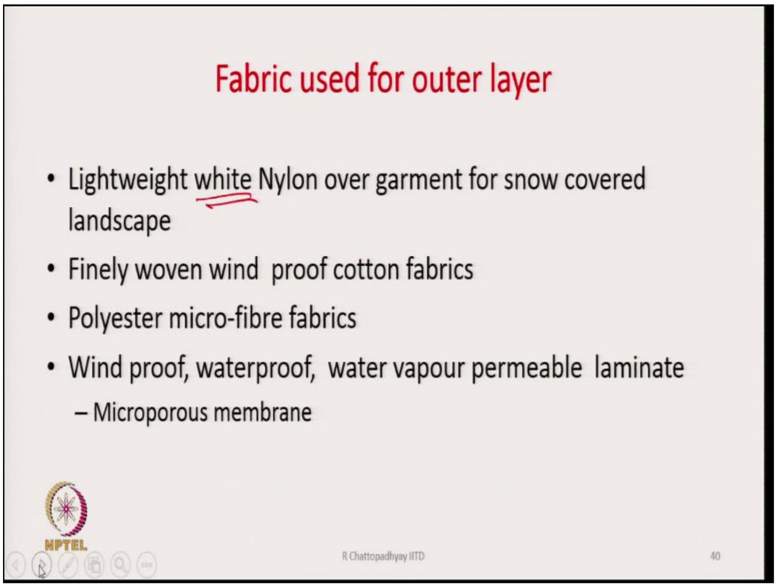


Finely woven windproof cotton fabrics can also be used for outer layers. Additionally, polyester microfiber fabrics are available, offering windproof and waterproof properties along with water vapour permeability. These features are often achieved through microporous laminates.

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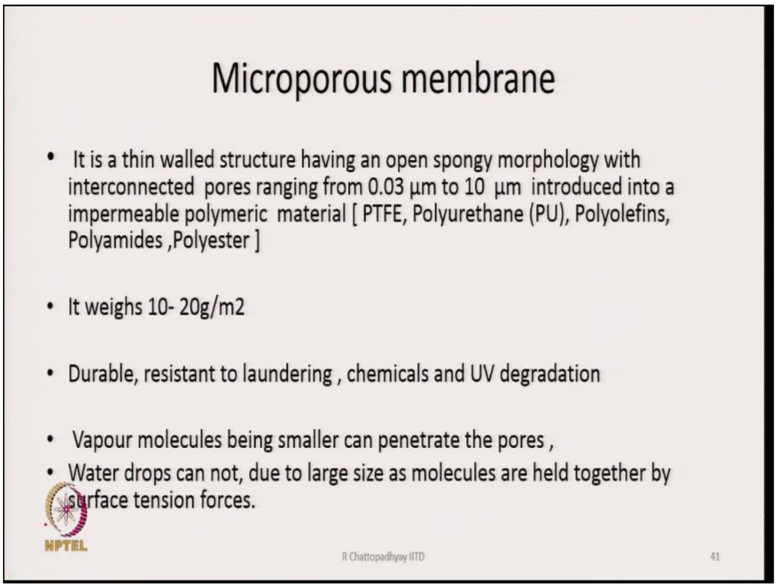


Next is the microporous laminates or microporous membranes. It is a thin wall structure having an open spongy morphology with interconnected pores ranging from 0.03 to 0.10 µm. The pore sizes are extremely small and are introduced into impermeable polymeric materials such as PTFE, polyurethane, polyolefins, polyamides, and polyester. These microporous membranes are widely available.

The typical weight of microporous membranes ranges from 10 – 20 g/m$^2$. These membranes are thin, durable and resistant to laundering, chemicals, and UV degradation. Vapour molecules can penetrate the pores because they are significantly smaller than the pore sizes. In contrast, water droplets cannot pass through due to their larger size, which is influenced by surface tension that holds the water molecules together, resulting in a larger drop size.

In vapour form, water molecules are very small, allowing them to pass through the micropores of these membranes, while larger water droplets cannot. As a result, these membranes have been specifically designed for such applications.

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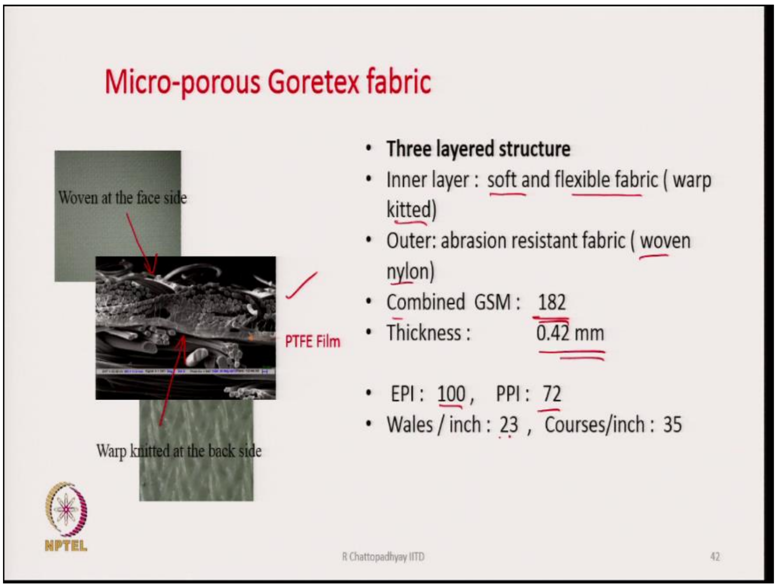


One example of this type of fabric is Goretex, which is illustrated in the cross-sectional diagram shown here. Gore-Tex is a three-layered fabric: the inner layer is a soft, flexible, warp-knitted fabric; the outer layer is typically made of abrasion-resistant nylon; and sandwiched between these layers is a PTFE film.

The combined weight of the Goretex fabric is 182 g/m$^2$, and the thickness is approximately 0.42 mm. The woven fabric features 100 EPI and 72 PPI, while the wale/inch and course/inch are around 23 and 35, respectively. These construction values of the Goretex fabric are used in many applications, especially in situations where protection from raindrops is essential while still allowing moisture vapour to escape.

Goretex is a commercially successful composite fabric with a central PTFE film, which is very thin and sandwiched between two layers of fabric. Therefore, this can be used in the outer layer. This lecture concludes the discussion on the various aspects and considerations of designing winter clothing. When designing a particular item for extreme cold weather, many aspects must be considered.

The ensemble includes various components, such as socks, gloves, and caps, which are not ordinary day-to-day design items. Each of these items must be carefully designed, particularly for their insulation properties. Normal socks, for instance, may not provide the necessary insulation for extreme cold weather. Therefore, it is essential to consider the design of all items that a person will wear in such conditions.

The discussion here has primarily focused on the jacket component of the ensemble. The ensemble consists of multiple layers, from the base to the mid-layer and finally the outer layer. However, while the jacket covers only part of the body, the rest of the part of the body also needs to be covered. Trousers, gloves, hats, socks, and shoes must be carefully designed to meet the required properties. This design exercise is extensive, and some guidelines have been stated that enable the development of effective design solutions. Thank you.