SCIENCE EDUCATION SERIES
No. 6

PHYSIOLOGY OF CLOTHING

by

V. Basnayake

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47/5 Maitland Place
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FOREWORD TO THE SERIES

The dissemination of scientific information is one of the main functions of the National Science Council. The National Science Council Journal provides a medium for the publication of scientific research papers, while "Vidurava," the quarterly science bulletin of the National Science Council, contains scientific articles of a general nature which are of interest to the public.

There is still a wide gap in the availability of reading material on scientific subjects of local interest. One result of this is that science students confine their reading only to their school notes and to the few available text books which are mostly published abroad. In an attempt to improve this situation, the Science Education Research Committee (SERC) of the National Science Council decided to publish a series of booklets on scientific topics of local interest as supplementary reading material for students and the general public. The authors who have been selected by the Committee to prepare these booklets are experts in their respective fields. The manuscripts that were submitted by the authors were examined by referees before being accepted for publication. The views expressed in these publications are those of the authors and not necessarily those of the National Science Council.

In conclusion I must thank the Science Education Research Committee of the National Science Council, and in particular its Hony. Director, Prof. K. Jayasena, for the work they have put in to make this project a success.

R. P. Jayewardene
Secretary-General
National Science Council of Sri Lanka

14 November, 1980.

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Chapter 1

WHY DO PEOPLE WEAR CLOTHES?

Writers on clothing point out that the main reasons for wearing clothes are psychological rather than physiological (Fluegel, 1950; Laver, 1952). "Clothes are not primarily the covering of the body, they are the vesture of the mind" (Laver). There are still other considerations which determine the choice of clothing, such as the availability of water and soap for washing clothes, the costs of laundering, and similar matters of feasibility. There is also the factor of commercial exploitation by the textile trade under the guise of *couture, haute* or otherwise.

The psychological reasons for clothing may be given as follows:

a) Decoration and display

i. The hierarchical principle

ii. The seductive principle

b) Modesty - the fig-leaf principle

1.1 *The hierarchical principle* is that clothing is a device to display inoffensively the wearer's place in the social hierarchy (Figure 1). It is not only in the army and police that hierarchies and hierarchical clothing exist. In the Perahera walk the Nilames are heavily padded while their lackies are bare-chested. In the medical profession, consultants dress in a more distinguished manner than the lower ranks. Matrons, sisters and nurses can be distinguished by their uniforms. In our society, gentleman (mahathwaru) wear trousers, others the sarong. Ladies (nonamahathiwaru) wear saree or frock, the others cloth and jacket. Labourers seek to become trouser-wearers (kalisangkarayas), passing via short trousers to longs. Bishops wear red and mitre, others black and cap. The Buddhist clergy seems to have escaped from the hierarchical principle. Persons may display cleanliness by wearing white, and wealth by wearing expensive fabrics. In the days of kings and peasants in old Lanka the peasant wore a cotton cloth (saluwa) from waist to knee and that was all.

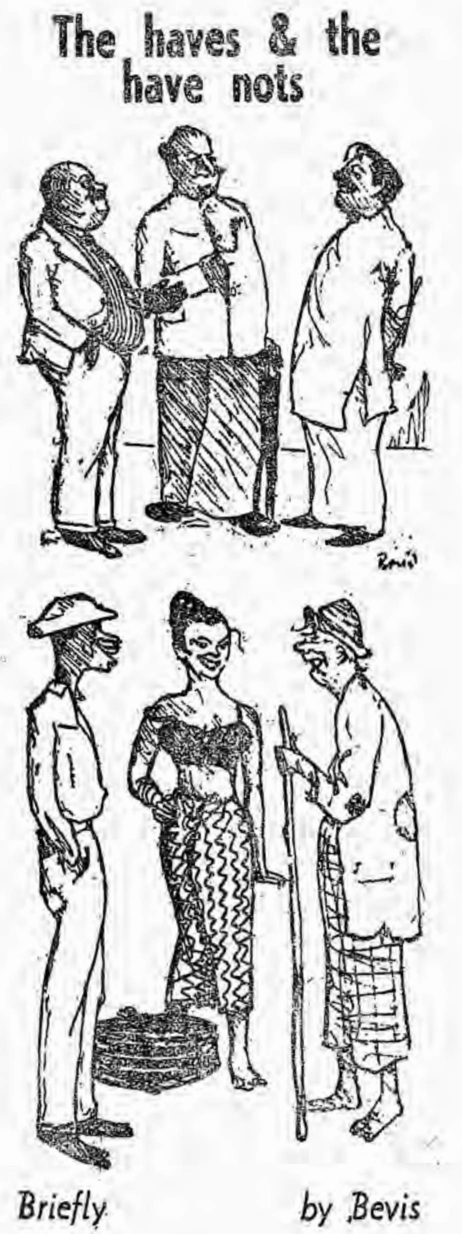


Figure 1

The wearing of garments which covered the chest or went below the knee were prerogatives of royalty and chieftains. When Mr. Tissa Wijeyaratne proposed in 1960 that lawyers should be allowed to wear the so-called national costume in place of coat and tie and trousers there was a cry from the Establishment: one lawyer declared "Let us be sensible, I am quite comfortable in the dress I appear in court"; another lawyer said of the proposal, "It's ridiculous rubbish"; and still another said that the existing dress should be retained because it gave lawyers a sense of dignity. Figure 2 shows the variety of formal male costumes which were jostling side by side in the Ceylon of the 1930's. Has there been any notable change during the 40 years which have passed since then?

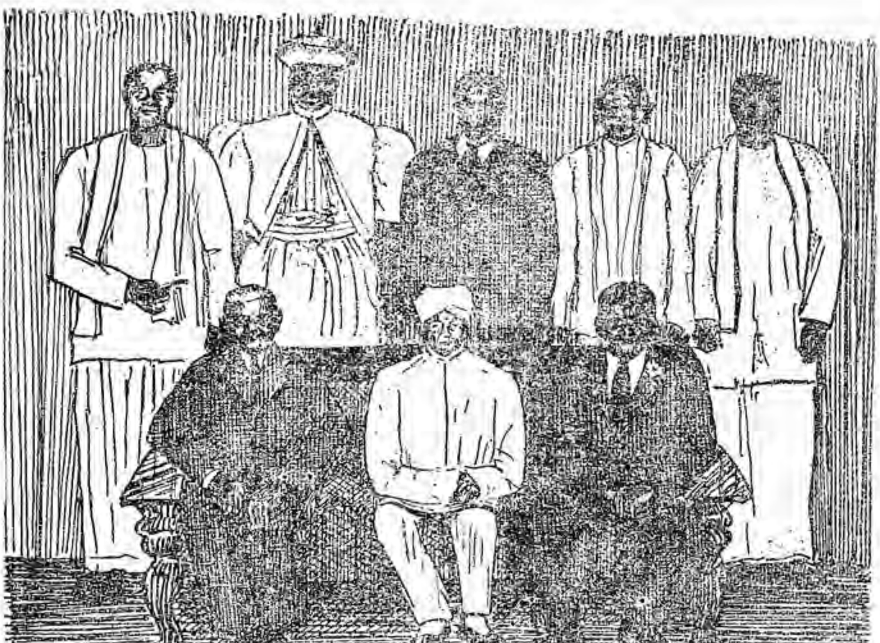


Figure 2. — Formal male attire in Ceylon in the mid 1930's. (after a photograph in the *Times of Ceylon*, 23.1.1961).

1.2 *The seductive principle* is that clothing is a powerful means of attracting others, often those of the opposite sex. Gerald Heard was inclined to regard clothes as being a part of the secondary sexual

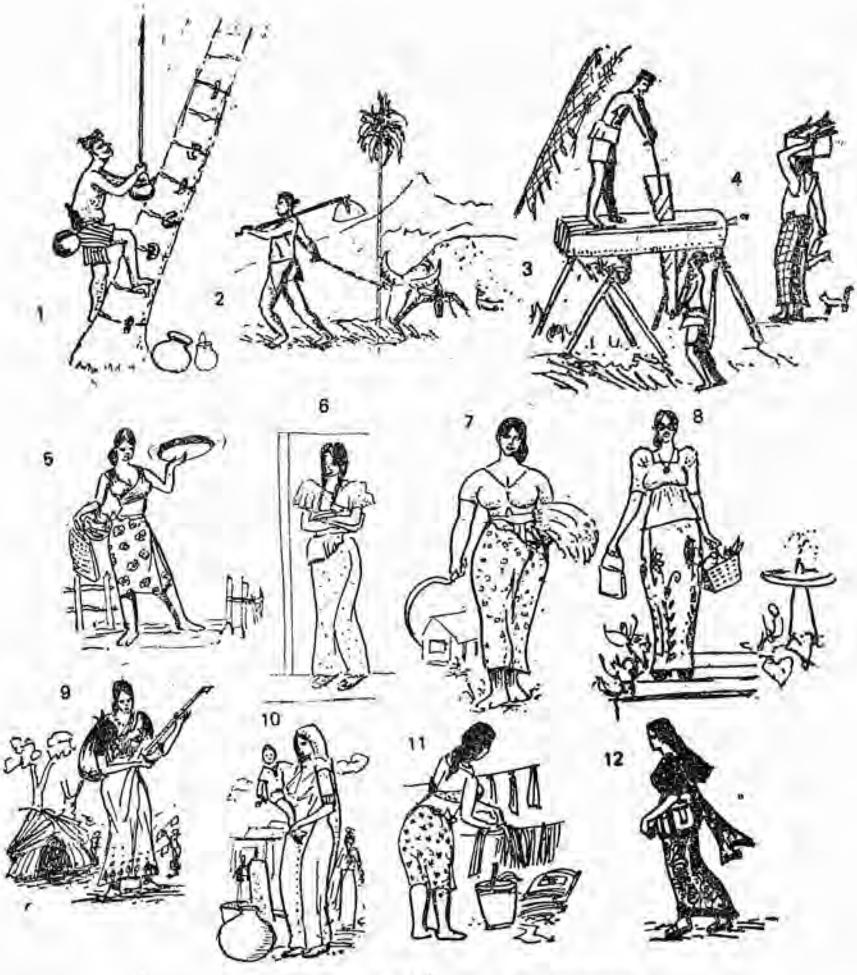


Figure 3. — Class work & clothing

1. Coconut toddy tapper
2. Spancloth of cultivator
3. Saruwalaya of sawyer
4. Sarong & banian of vendor
5. Rodiya woman
6. Lama sariya (half saree) of Kandyan schoolgirl
7. Redda hattay (cloth & jacket) of village woman
8. Lungi of a town woman
9. Ahikuntakaya (gypsy) woman
10. Saree of a Muslim woman
11. Rodiya woman
12. Saree of Kandyan woman.

characteristics. Art is used to display nature by concealing it. Brassieres, bikinis and minifrocks are the more obvious examples of the seductive principle which hardly leaves any aspect of female attire untouched.

1.3 *The modesty principle* is seen in its purest form in the spancloth (a word which you would not find in *Chambers' Twentieth Century Dictionary* or in *Websters' New World Dictionary* although both have its synonym, loincloth). *Carters' Sinhalese-English Dictionary* has the entry: "amudaya, amuday, n. a man's fore-lap, a piece of cloth worn over the privities, 'span-cloth' ". Many garments that seem to exemplify the modesty principle are in fact subtle examples of the seductive principle.

1.4 *Custom.* It is not to be supposed that all of us are conscious of the hierarchical principle, the seductive principle and the modesty principle when we get our clothes. This is usually done according to the prevalent customs (figure 3). We simply fall in line with custom. The point, however, is that behind the face of custom lie these principles of hierarchy, seduction and, to a very limited extent, modesty.

Chapter 2

THE PHYSIOLOGICAL FUNCTIONS OF CLOTHING

The *physiological functions* of clothing lag far behind the psychological.

2.1 *Pure physiological clothing.* The purest forms of physiological clothing are seen in space suits, arctic clothing and clothing for survival in icy waters. These are situations where men are placed in desperate conditions and everything passes into insignificance beside the brute fact of mere survival.

2.2 *Physiological considerations in clothing.* Physiological considerations have some little chance of coming into play in everyday life. This happens in circumstances where the hierarchical and seductive principles lose their sway. We may expect to find traces of it in the clothing that we wear when we are, say, in the rain, or when we are by ourselves, powerless to show our status, powerless to seduce, and with no one around who would care to observe us except the mosquitoes. Such is the case when we are in prison or in our lonely bed chambers. But even here the hand of custom tends to drown the physiology.

It will be granted, nevertheless, that there are physiological principles which should govern the design of clothing, other things being equal. It is true that other things are seldom equal. If physiology conflicts with the psychological principles of hierarchy, seduction and modesty, it is physiology which is thrown out. Thus in the design of army clothing a less physiological fabric may be preferred to a more physiological one, simply because it is more attractive to the girls. However, if two costumes both satisfy psychology, the choice between them could be influenced by physiology.

Chapter 3

PHYSIOLOGICAL OBJECTIVES IN REGARD TO CLOTHING

Physiological objectives in regard to clothing may be listed as follows:-

3.1 *Skin functions.* Clothing should not hinder the functions of the skin.

3.1.1 *Barrier function* of the skin
Clothing should *allow insensible water vapour loss* to take place
Clothing should not allow *microorganisms* to grow on the skin
Clothing could protect against *mechanical injury* including insect bites

3.1.2 *Sensory functions*
Clothing should not abolish the *sensitivity* of the skin

3.1.3 *Thermoregulatory functions*
Clothing should not imprison the *body heat* or extract it excessively
If posible, clothing should do better than the natural physiology to prevent undue heat loss or heat gain
Clothing should promote *thermal comfort*

3.2 *Weight.* Clothing should not add unnecessarily to the body weight

3.3 *Posture and movement.* Clothing should allow us to sit, stand and move naturally

3.4 *Deformities and distortions*
Clothing should not give rise to *anatomical deformities* and *physiological distortions.*

The following pages discuss these objectives in terms of the available data.

Chapter 4

ANATOMICAL DEFORMITIES FROM CLOTHING

4.1 *Ornaments* are frequently associated with wilful anatomical deformities. The ears and nose are bored for the insertion of rings Extra hair is piled upon the head.

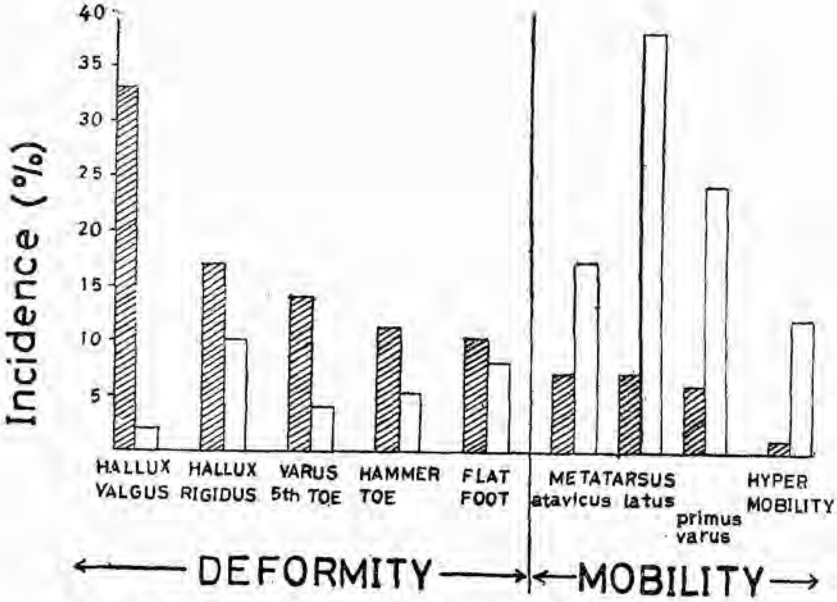
4.2 *Footwear*. Everybody has heard the old traditional tale about the way the Chinese used to keep their feet delicate and diminutive by confining them in little shoes. But what about ordinary shoes? Can they give rise to anatomical deformities? There was a spate of correspondence in the *British medical journal* in 1960 about footwear. A survey done in Stirlingshire in 1958 showed that the incidence of deviation of the toe (hallux valgus) was related to age and sex (table 1). The difference in the incidence of hallux valgus between boys and girls at the age of 15 was attributed to some difference in footwear habits, such as the use of small shoes or high-heeled shoes by girls. Another survey of the incidence of hallux valgus reported that 75 per cent of girls leaving school in Britain had the condition (Payne, 1957). A study done in Hong Kong in 1958 showed that shoe wearers had more deformities and less mobility of the feet than non-wearers (Figure 4).

TABLE I

Incidence of diviation of toe (hallux valgus) in boys & Girls.
Survey in Stirlingshire, 1959,
(cited in **British medical journal,** 1960, **1**, 488)

Age (years)	Incidence	
	Boys (%)	Girls (%)
5	2.3	1.6
15	14.8	54.6

What is this difference between boys & girls due to ?



Incidence of deformity & abnormal mobility among wearers and non-wearers of shoes. Hong Kong survey, 1958. British medical journal, 1960, 1, 1279.

Figure 4

Ringworm of the foot (tinea pedis) is said to be much more common in people wearing socks and shoes in the tropics (Desai & Bhat, 1961).

4.3 *Foundation garments.* The incidence of varicose veins in a group of English factory women was found to rise significantly according to whether they wore garters or suspender belts, roll-on belts, or corsets.

	Per cent of subjects who had varicose veins
Garters	21
Suspender belts	18
Roll-on belts	31
Corsets	46
Overall incidence	32

The incidence of varicose veins in Egyptian factory women (in Egypt) was low (about 6%) and these women wore no foundation garments or only garters in the winter season. This evidence suggests that corsetry increases the risk of developing varicose veins. It is speculated that this is because the corset or roll-on "constrict the abdominal wall, slow the circulation in the lower limbs, and raise intravenous pressure" (Mekka *et al*, 1969).

Chapter 5

PHYSIOLOGICAL DISTORTIONS

Physiological distortions short of anatomical deformity may be produced by changing the environment of a tissue or organ. Male underwear may produce oligospermia (reduction in sperm count in semen) (LIFE, 1967). This is attributed to the action of undue warmth upon the testis. Rings on the finger may produce vascular obstruction. Tight abdominal clothing may change the pattern of breathing. Thermal functions are discussed later (chapter 8).

Chapter 6

WEIGHT OF CLOTHING

The weight of clothing of even a lightly clad tropical man may be of the order of $1\frac{1}{4}$ kg (2/8 kg shirt, 3/8 kg trousers, 5/8 kg sandals, 1/8 kg underwear, not to mention the utility display article of a wristlet watch). Carrying a weight around has to be paid for by eating more. Measurements of Air Force garment assemblies have shown that heavy garments add to the metabolic cost of work. The weight of clothing worn by patients might be expected to reduce the deterioration in physical fitness which occurs during bed rest, but measurements have not given support to the idea (Vogt et al., 1967).

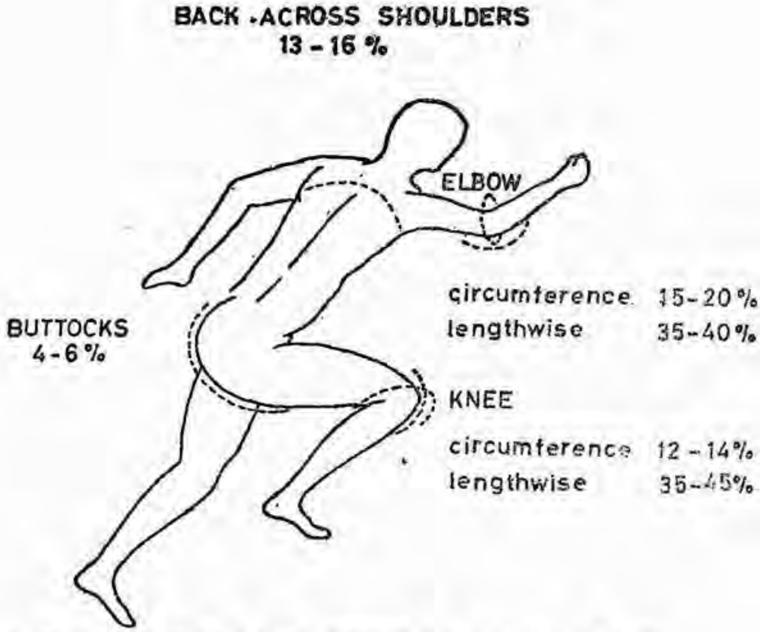
Chapter 7

CLOTHING AND MOVEMENT

A saree may restrict movement (Fig. 5).

Figure 5. — Saree

The textile trade has worked out the leeway that should be allowed in garments for freedom of movement (Fig. 6).



The amount of extension that should be allowed for in garments during movement. (Textiles: fiber to fabric. Potter & Corbman New York: Gregg McGraw-Hill, 4 ed. 1967 p.403)

Figure 6

Arthur Clarke wrote of the sarong:

"I shall always remember Weligama as the place where I learned to wear a sarong, a garment which up to that date I had chiefly associated with Dorothy Lamour and had certainly never regarded as an article of male attire.

"The sarong consists of a simple tube of cloth about four feet long and seven feet in circumference. It is not a very good fit around the waist for a normal human being; when you stand up inside up inside it, you are a couple of feet away from it in every direction. To keep it in place it is pulled tight, the surplus length is folded across the front of the body, and the end is tucked in at the left side. This operation takes half a second to perform, but as a rigorous topological description of the process would require several pages, anyone who has not got the idea by now will simply have to take it for granted that a sarong can be fooled into holding itself up.

"However, unless the original loop is drawn very tightly round the waist, and the overlap is correctly arranged, disaster quickly strikes. You may take perhaps two or three paces, and then you will feel a sudden lessening of tension round your midriff. The end of the tuck creeps slyly out, and before you know what has happened a kind of sartorial chain reaction has taken place. Unless you are quick on the grab, you will be unveiled like a statue in the park when the mayor pulls the cord after his speech of dedication.

"It is advisable, therefore, to practice wearing the sarong in private until you have mastered it. After a while you will discover how to anticipate and prevent its imminent collapse by a kind of quick shimmy and a few dexterous twists of the wrist. When you have reached this stage, it is safe to venture outdoors.

"Because of its simplicity, its comfort and the speed with which it can be put on and taken off, the sarong is ideal for housewear in tropical climates; once I had discovered it I never wore anything else. But out of doors it has disadvantages, which in my case I concede may have included the aesthetic. You cannot hurry in it, for apart from its natural instability (unless you cheat by wearing a belt, as in fact everyone does) it prevents the lower limbs from taking a full stride. So when the Ceylonese peasant is in a hurry, he has to hold up the hem of his sarong with one hand - an action which often looks unpleasantly effeminate. And when he wants to get into a fight, he has to tuck up the whole affair around his waist to give himself complete freedom of action.

"The upper-class Ceylonese, and anyone who is anything in the city, even if he is only a post-office clerk, wears ordinary European dress. Since trousers are a perfectly ridiculous lower garment for tropical climates, a vast amount of discomfort is caused by this form of snobbery. Having no reputations to maintain, Mike and I could always wear shorts when we travelled around; the European clothes we had brought with us we never wore once during our entire stay."

Chapter 8

THERMAL ASPECTS

8.1 Body temperature: heat gain and heat loss

Body temperature is maintained by striking a balance between heat gain and heat loss. *Heat gain* comes from metabolic heat production and from the environment if this is hotter than the skin, or if it is full of radiant heat from hot objects such as the sun or a kitchen fire. Metabolic heat amounts to about 1 kilocalorie (4.2 kilojoules) a minute when we are sitting at rest in a comfortable place. This is roughly the same as the heat emitted by an 80 watt electric bulb. Metabolic heat production is about 3.3 kcal/min when we walk, 6.3 in running, and it is greatly increased in stronger muscular activities, reaching a peak of 65 kcal/min in the most extreme spurts of muscular effort which cannot be sustained for more than a few seconds.

Heat loss takes place mainly from the skin (at least 85% of the total heat loss under comfortable conditions without sweating), to a lesser extent in the exhaled air (about 11%) and the rest of it in urine and faeces. The heat loss from the skin takes place by the physical processes of conduction, convection, evaporation and radiation. Conduction is ordinarily negligible because we are surrounded by bad conductors of heat, the chief of which is the air, including the air in our clothing. Evaporation accounts for about 25% of the total heat loss under resting non-sweating conditions. It comes from the insensible loss of water, in the form of invisible water vapour, from the skin. When we sweat, the heat loss from the body occurs mainly by evaporation. Over 95% of the total body heat loss may then be from the skin. It is regarded as a 'sensible' loss because sweat is often visible and wets the skin. The insensible perspiration ceases when the skin is wet.

The contribution of the different parts of the body to the total heat loss from the skin is, in the unclothed body, roughly in proportion to the surface area of the part. The head loses heat at the rate of about 75 kcal/m^2/h, in a resting person in a comfortable environment, i.e. at about twice the rate of heat loss from the body surface as a whole. In a cold environment, half the body heat loss may take place from the exposed head. The chest is warmer than the limbs and it contributes correspondingly more to the heat loss. The hand loses a great deal of heat under comfortable and warm conditions and also under very cold conditions (because of cold vasodilatation).

8.2 Physical principles in regard to heat exchange via clothing.

8.2.1 If clothing is not to hinder the process of heat loss from the body it should allow the heat to flow off the skin through the vents in the clothing and through the substance of the clothing (Fig. 7). The heat loss through the vents in the clothing occurs by convection ; the air warmed by the skin rises and passes out through the vents. Ventilation of the skin by the bellows action of moving garments, aids the process. The heat loss through the substance of the clothing takes place when the garment takes up heat from the skin (by radiation , convection and conduction from the skin), itself becoming warm and then emitting heat to the environment by radiation and convection.

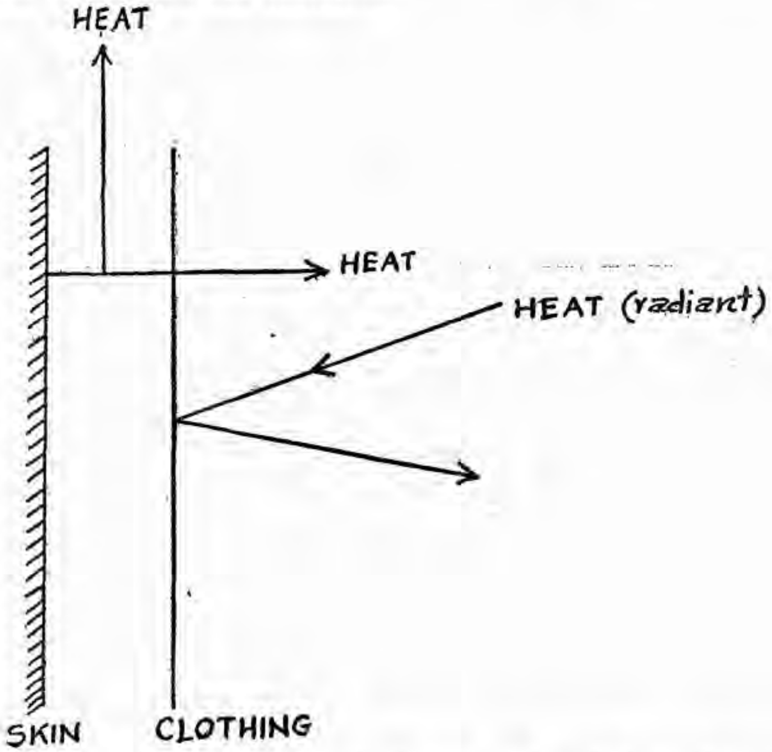


Figure 7. — Heat loss through clothing, and excluding of environmental heat

Clothing should allow evaporation from the skin. Evaporation occurs into the air space between skin and garment. This is increased by ventilation of the air space. Evaporation also occurs from the garment itself if it soaks up sweat and then evaporates it into the air.

8.2.2. Clothing does affect the heat loss from the skin it covers. A katathermometer (Fig. 8) can be used as a simple model

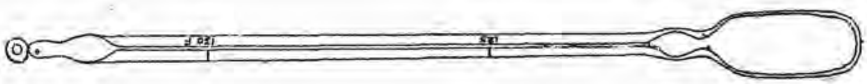
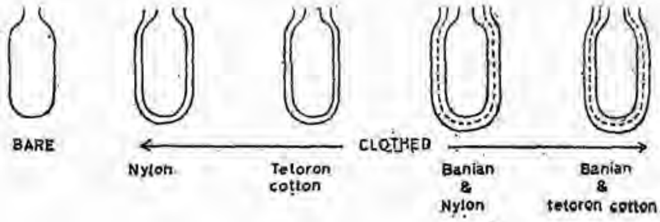


Figure 8. — Katathermometer

to show it. The katathermometer is one of the simplest instruments. It was devised by an English physiologist Leonard Hill, as a comfort meter and to measure air speed. The bulb is a simple model of the human body. It is warmed, suspended in the atmosphere, and the time in seconds that it takes to cool from 100F to 95F is called the "cooling time' of the atmosphere. *Cooling time* depends on the hotness and humidity of the atmosphere, air movement and shape and size of the bulb. By dividing the cooling time by a certain factor which is inscribed on the stem of the particular katathermometer we get the *cooling power* of the atmosphere in millicalories per square centimetre per second. The katathermometer is read (a) with the bulb dry (dry kata) and (b) with the bulb dressed up in a wet bag of cotton netting like a wet banian (wet kata). The wet kata reading is much less than the dry, because the cooling of the bulb occurs not only by radiation and convection but also by evaporation. From the dry kata reading and the dry bulb temperature of the atmosphere it is possible to estimate the *air speed.*

For our present purpose we can dress up our katathermometer to see what hindrance the clothing offers to heat loss from its body. Figure 9 shows some typical readings. The data give some indication of the hindrance which clothing offers to heat loss from the body.

Cooling time of bare or 'clothed' Katathermometer



COOLING TIME (seconds)	Bare	Nylon	Teloron cotton	Banian & Nylon	Banian & teloron cotton
Morning	164	212	200	246	186
Afternoon	206	299	331	348	297

Figure 9. — Cooling time of bare or 'clothed' Katathermometer

We cannot do this simple experiment on ourselves because of the complexity of the human body. A local hindrance to heat loss becomes compensated by alterations in blood flow locally as well as generally and by evaporation, so that total heat loss is maintained more or less at its proper level.

We, can, however, make a simple estimate of the insulating effect of clothing on heat outflow from our skin by measuring the temperature of the skin surface, garment surface and the air (Fig. 10). Take the analogy of a flow of electric current. $R = E/C$ where C is current flow, E is the electromotive force and R the resistance to current flow. Likewise for heat flow from skin to the atmosphere,

$$I = \frac{(T_s - T_a)}{H}$$

where I is the resistance or insulation of the atmosphere to heat flow, H is the heat flow and T_s the skin temperature and T_a the atmospheric temperature.

If the garment were a perfect conductor with no insulating effect at all, its surface will be tantamount to an extension of the skin surface and T_s will be equal to T_g, the temperature of the surface of the garment. If the garment were a complete barrier

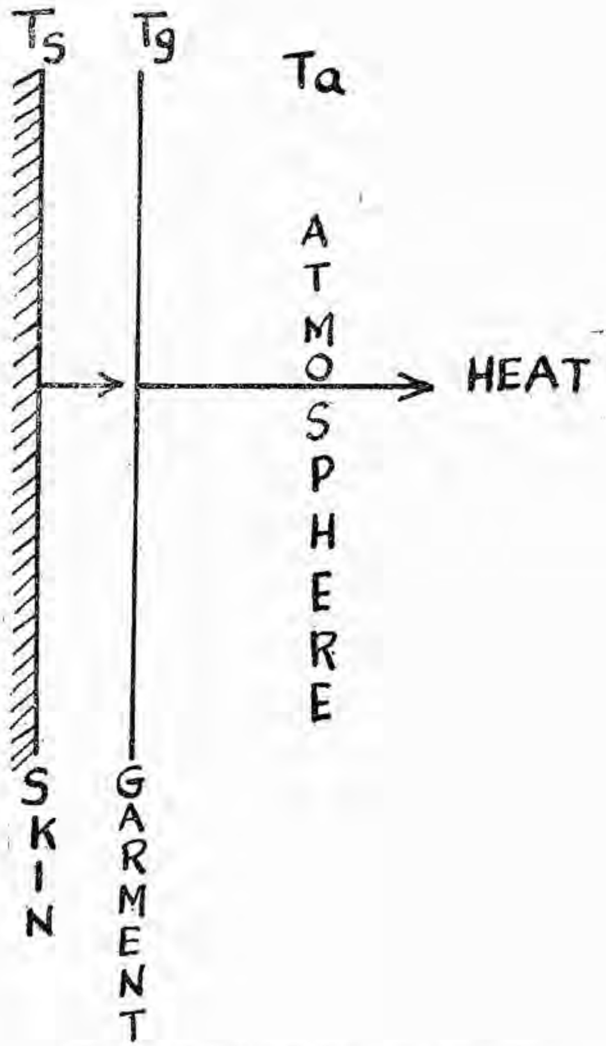


Figure 10. — Heat flow across garment

to heat flow, the surface of the garment would get no heat from the skin and it would be at the same temperature as the atmosphere, i.e. $T_g = T_a$. In short, the bigger the insulating effect of a garment, the bigger would $T_s - T_g$ be and the smaller would $T_g - T_a$ be. We can estimate the effect by calculating the percentage

$$\frac{(T_s - T_g)}{(T_s - T_a)} \times 100$$

The bigger the percentage the bigger the insulating effect of the garment. A perfect insulating garment would give the value 100%. A perfect conductor would give 0%.

Table II shows readings made in this way. The temperature

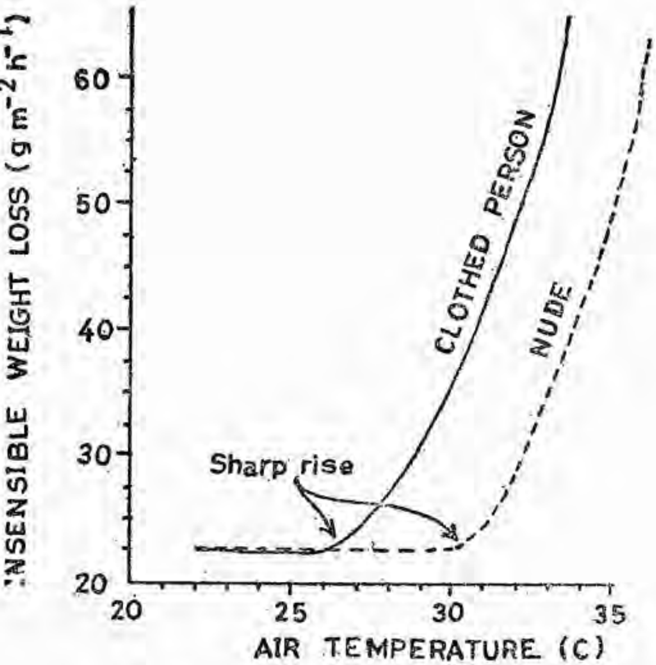
TABLE II

Insulating effect of clothing

Garment	Temperature of Skin surface T_s (°C)	Temperature of garment surface T_g (°C)	Temperature of air T_a (°C)	Insulation effect of garment $\frac{(T_s - T_g)}{(T_s - T_a)} \times 100$ %
Banian	35.6	34.8	28.1	11
Shirt	34.8	33.3	25.4	10
Overcoat	35.3	33.6	26.5	19

readings were taken by means of a thermistor. We may conclude that a garment such as a shirt or a banian does offer resistance to heat flow from the skin which it covers. Its magnitude is of the order of 10%, if a complete insulator is denoted by 100%.

Fig. 11 shows another piece of evidence that ordinary clothing



Sharp rise in 'insensible weight loss' in warmth

(Journal of applied physiology, 1963, 18, 1108)

Figure 11

throws a physiological stress on the body. The clothed subjects had worn light-weight clothing. The sharp rise in the line is presumably due to sweating. The rise begins at 26.7 C air temperature in the clothed subject and only at 30 C in the nude subject.

8.3 Factors affecting heat exchanges via clothing

We may list these as follows :

Fibre
Fabric
Colour
Garment
Number of layers of clothing
Ventilation of the skin
Other factors e.g. wet clothing

8.3.1 *Fibre.* Clothing fibres may be classified as follows:

Plant fibres	Cotton, linen
Animal fibres	Silk, wool
Man-made fibres	
Cellulosic	Rayon
Synthetic	
Acrylic	
Olefin	Polypropylene
Polyamide	Nylon
Polyester	Terylene (Dacron)
Polyurethane	
Polyvinyl	
Mineral	
Metallic	
Rubber fibre	

Plant fibres include cotton (from the seed hairs of the cotton plant), linen (from the stem of flax), and less common fibres such as ramie (from the stem of a plant *Boehmeria nivea*), pineapple (from the leaf), and bark cloth (which used to be the dress of Veddahs), Animal fibres include wool and silk, and less common fibres such as mohair and alpaca. Man-made fibres may be classified as *cellulosic* fibres (rayon acetate and triacetate), *synthetic* long-chain polymer (polyamide or nylon ; polyester such as terylene or dacron ; acrylic such as orlon ; polyvinyl such as saran ; etc.), and certain less common fibres from metal, glass, etc.

For our purpose it would be of little use to study the properties of fibres. The physiology of clothing depends more upon the kind of fabric into which the fibre is woven and finished, even more upon the kind of garment into which the fabric is tailored, and still more upon the number of garments in the clothing assembly covering the skin. It is the air trapped in and under clothing that is the chief factor insulating the skin from heat loss. Warm blankets are made from cotton, and cool net blouses from nylon. Glass is a good conductor of heat – so we don't drink hot tea out of a tumbler – but a mass of glass in fibre form traps so much air as to turn it into a high-class insulating material. Fabrics contain much more air than fibre: 80 per cent of the volume of a fabric may be air. Furthermore the thermal conductivity of fibres is much nearer that of air than of good conductors such as metal (Table III).

TABLE III

Thermal conductivity of materials

Material	Thermal conductivity (KMH units)*
Metals	
Silver	36000
Copper	18100
Textile fibres	
Cotton	20
Cottonwool	2
Linen	7
Silk	7
Wool	4
Other materials	
Leather	14
Rubber	18
Sponge rubber	7
Air	2

* k cal $m^{-2} h^{-1} cm^{-1} s^{-1}$

TABLE IV

AFFINITY OF TEXTILE FIBRES FOR WATER

Degree of affinity	Moisture content (%)	Imbibition of water (%)	Textile fibres (& their imbibition value)
High	> 10	> 50	Viscose rayon (100 %) Linen (60 %), Wool (50 %) Silk (50 %)
Moderate	5–10	30–50	Cotton (45 %), acetate rayon (30 %)
Low	1–5	10–30	Polyamide (nylon 13 %)
Very low	< 1	< 10	Acrylic Polyester (terylene 5 %)

Moisture content:- Weight of water in g per 100 g fibre in air at 21°C & 65% R.H.

Imbibition:- Amount of water (g) taken by up fibres (100g) after soaking in water.

The *water absorbency* of fibres is importance. The synthetic fibres, such as polyamide (nylon) and polyester (terylene) are hydrophobic. Raincoats are often made of a 100% synthetic fibre such as terylene or nylon. Terylene is one of the least absorbent of fibres. It dries fast because the water is not absorbed. Cellulose fibres are generally hydrophilic. This is true of cotton, linen and rayon, but no so much of acetate fibre. Sweat is easily absorbed by hydrophilic fibres and evaporated off into the air. Sweat is not easily absorbed by the hydrophobic synthetic fibres. Under conditions of sweating, therefore, cotton and rayon are physiologically superior to the synthetics (other things such as weave and garment pattern being equal). This is why terylene is often blended with cotton in textile manufacture. Wool absorbs well but dries slowly. Silk is also a good absorber of water and can hold much water without giving rise to the feeling of wetness. In a test of six upholstery materials for office chairs, the accumulation of sweat in the men's bottoms increased in the following order:- wool, 'dralon', leather, and three kinds of polyvinyl plastic sheet (Burandt & Grandjean, 1968).

8.3.2 *Fabric*

Fibres are turned into yarn (by the process of spinning) and the yarn into fabric (by weaving, knitting or other process) (Fig. 12). The fabric is subjected to finishing processes (such as bleaching, mercerizing, shrinking, and shape-retentive finishing).

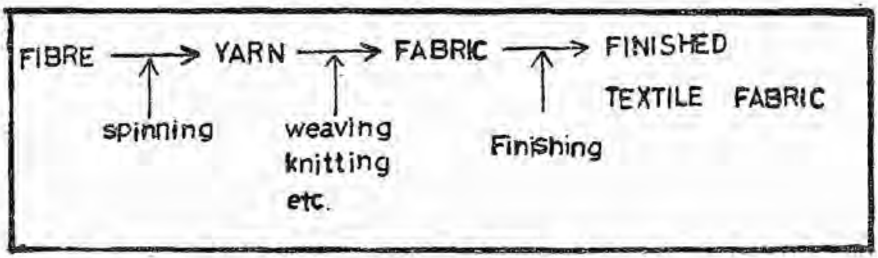


Figure 12. — Fibre to fabric

Fig. 13 indicates something of the great variety of woven textiles that are in use. The heat insulation effects of fabrics are therefore very various. Table V shows the thermal insulation values of some cotton fabrics.

TABLE V

Thermal insulation value (TIV) of cotton fabrics

Fabric	TIV (%)
Cotton, singles poplin	25
warp pile	72
plain weave, raised	52
2/2 twill, raised	44

In general, the thinner the fabric and the looser its weave, the less will be its heat-insulating effect, and the greater will be its porosity to air and water vapour. The thicker the fabric and the greater its air content, the greater will be its heat-insulating effect. A simple demonstration can be made of thefact that weave of fabric is far more important for water permeability than is the kind of fibre from which the fabric is made. Place 30 ml of water in each of a series of 50 ml

WOVEN FABRICS

- Basic Weaves
  - Plain weave
  - Twill weave
  - Satin weave
- Fancy weaves

Basic weaves

<u>Plain weave</u>

- <u>Simple plain weave</u> eg cambric, crepe, flanellette, gauze (surgical), muslin, sheeting, voile
- <u>Basket weave</u>
- <u>Ribbed weave</u> eg. poplin, taffeta

<u>Twill weave</u> eg. denim, drill, gabardine, jean, khaki

<u>Satin weave</u> eg. damask, sateen, satin

Fancy weaves

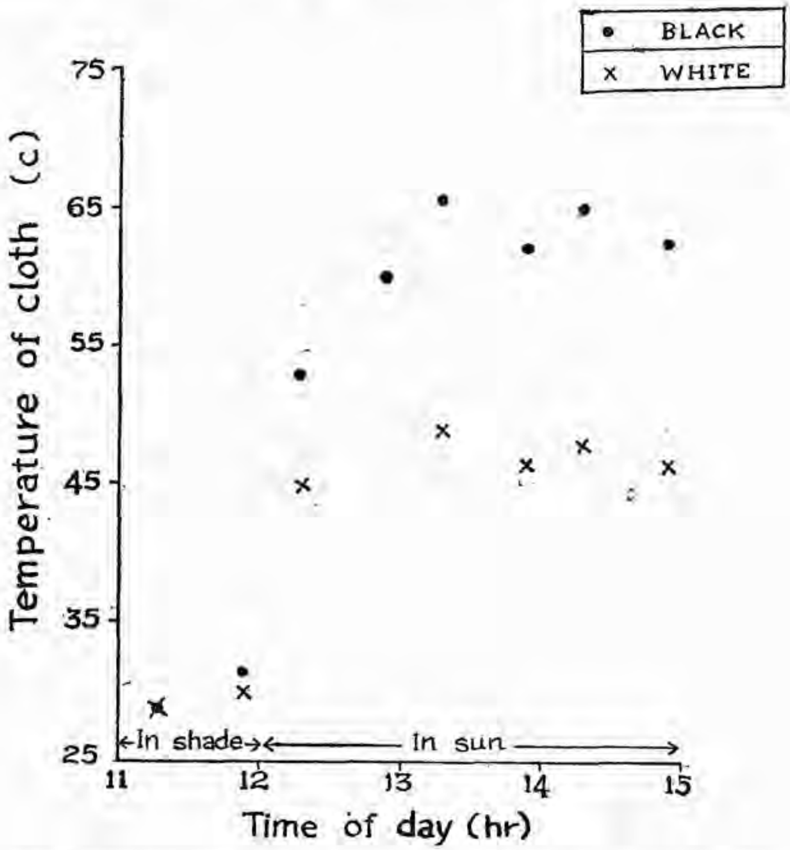
- Pile weave eg. corduroy
- Gauze weave eg mosquito netting
- Swivel weave
- Lappet weave
- Dobby weave
- Jacquard weave

Figure 13. — Woven fabrics

beakers. Cover each beaker by tying a fabric over the mouth of the beaker. Use a variety of fabrics made from various fibres. Put the beakers aside and note the water level at weekly intervals. It will be found that the water level falls (by evaporation) about equally in all the beakers.

8.3.3 *Colour*

White clothing wards off external radiant heat by reflecting it back to the environment. Black clothing, on the other hand, would



TEMPERATURE OF WHITE TUSSORE & BLACK TUSSORE EXPOSED TO THF SUN FROM NOON TILL 3 P.M.

Figure 14

absorb radiant heat. Table VI and Fig. 14 show the pattern of heating up of white and black fabrics upon exposure to heat. It is clear that black cloth absorbs radiant heat more than does white.

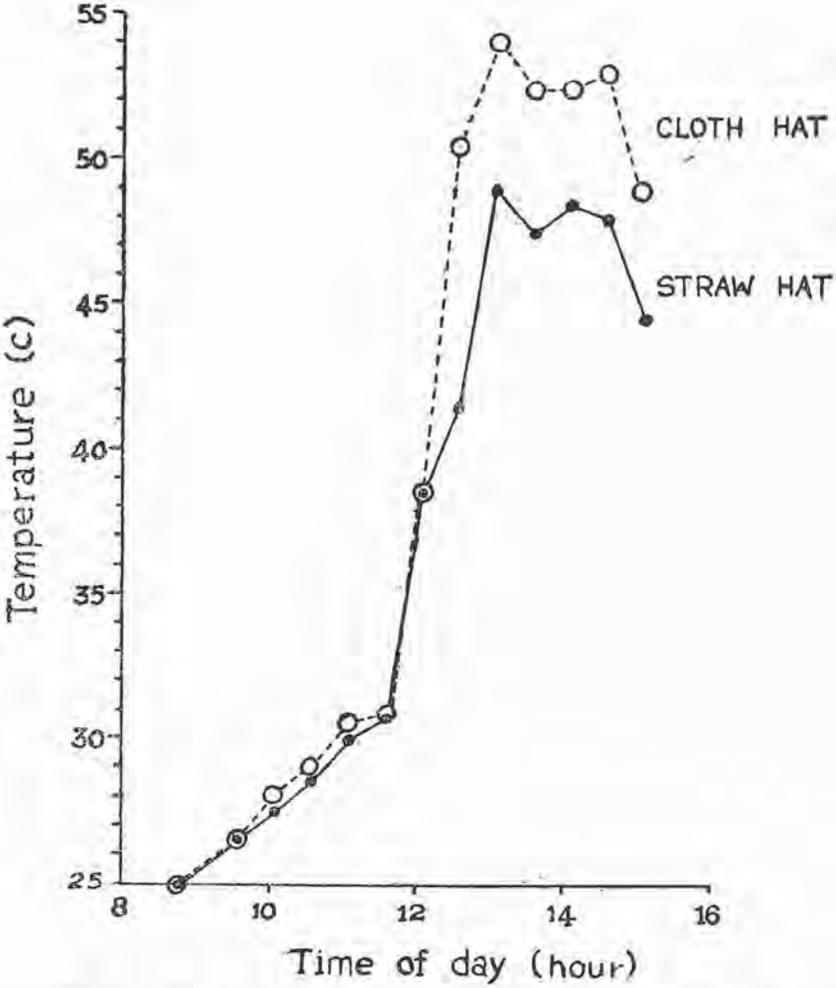
TABLE VI

TEMPERATURE RESPONSE OF BLACK & WHITE FABRICS TO RADIANT HEAT

Fabric	Time taken for temperature to rise 4°C (from 27°C to 31°C) (min)	Temperature increase in 10 minutes (°C)
Tussore, white	7.0	4.6
,, black	3.5	5.7
Voile, white	8.5	4.2
black	7.2	4.6

This is an excellent reason for avoiding black and wearing white in the sun. We might suppose that by the same token black could be better wear for the shade and the interiors of buildings, assuming that the walls are at a lower temperature than the skin; the black would radiate out the body's heat better than white. The effect is of little or no importance with relatively cool bodies like the skin which emits only long heat waves (unlike the short heat waves of hot bodies like the sun), and where convectional loss of heat is readily available to the body by means of loose open garments. Table VII shows the heat insulation effect of black and white cloth at ordinary room temperature. The cloth was placed on the thigh of a subject wearing running shorts. The data show (in the last column of the Table) that black is not warmer than white under ordinary room conditions. They even suggest that black may be cooler than white under these conditions.

Experiments with a straw hat and a khaki cloth hat gave the results shown in Fig. 15. They showed some slight superiority of the straw hat over the cloth hat with regard to the temperature of the air under the hat when the hats were exposed to radiant heat.



TEMPERATURE OF THE AIR INSIDE a HAT EXPOSED TO THE SUN.

Figure 15

TABLE VII

HEAT INSULATION EFFECT OF WHITE VS BLACK CLOTH (tussore)

Ta, Temperature of air
Tg, ,, ,, cloth
Ts, ,, ,, skin

Cloth	Ts (°C)	Tg (°C)	Ta (°C)	Insulation effect $\frac{(Ts-Tg)}{(Ts-Ta)} \times 100\%$
None	34.8	—	25.5	—
Black, 1 layer	34.6	34.4	25.5	2
,, 4 layers	34.8	33.8	25.9	11
,, 8 ,,	34.4	33.0	26.1	17
None	33.8	—	26.7	—
White 1 layer	33.8	33.0	26.8	11
,, 4 layers	34.2	32.6	26.9	22
,, 8 ,,	34.4	32.6	26.9	24
None	34.2	—	26.9	—

8.3.4 Garment

8.3.4.1 *Classification.* We may classify garments into three types

a) Garments which are *tied* to the body. E.g. sarong, trousers, saree, laced shoe, strap shoe.

b) Garments which are *hung* on to the body without tying. E.g. shirt, blouse.

c) Garments which are *pressed* into place.

  i. by their own elasticity. E.g. knitted garments such as vests, banians, socks and other hosiery, underwear, sweaters.

  ii. by external pressure or gravity. E.g. hat.

Hung garments give a better chance of ventilating the skin surface than tied garments because of the openings to the atmosphere which they can provide at their upper and lower ends. They may not be as efficient as knitted garments in absorbing sweat.

8.3.4.2 *Trousers.* Shorts were compared with overalls in the studies done by the British Medical Research Council team who set up a climatic physiology unit in Singapore during World War II. The subjects were naturally acclimatized British men. The overalls consisted of a one-piece blue drill suit. Both shorts and overalls were made of cotton. The men were exposed to heat stress in a climate chamber and their physiological strain measured in terms of sweat output, rectal temperature and pulse rate (Table VIII). In moderate heat (dry bulb temperature DB 90 F) the strain was greater with overalls

TABLE VIII

PHYSIOLOGICAL STRAIN OF SHORTS VS OVERALLS DURING EXPOSURE TO HEAT. MRC STUDY ON NATURALLY ACCLIMATIZED WHITE MEN IN SINGAPORE.

Experimental condition	Physiological indicator	Physiological strain Shorts(S) vs overalls(O)
Moderate heat(DB90°F) Resting	Sweat loss	O≡S 1.8 Kg 1.6 Kg in 4h
	Pulse rate	O≡S
Exercise	Sweat loss	O> S 3.3 Kg 2.6 Kg in 4h
	Pulse rate	O> but not significant
	Rectal temperature	O > S 101.1 100.6°F
Severe heat (DB120 F) Exercise	Sweat loss	S> O
	Pulse rate	S≡O
	Rectal temperature	S> O

than with shorts. The effect was clearer during muscular work than during rest. In severe heat (DB 120 F) with hot wind, the strain was greater with shorts than with overalls, presumably because overalls protected the body against heat gain from the hot air better than the shorts did.

8.3.5 *Number of layers of clothing*

a) *Two-layer and three-layer clothing.*

We presented evidence earlier (section 8.2.2 above) that a garment such as a banian or shirt has an insulating value of about 10 per cent. What happens if we wear two layers of clothing? It is like having two resistances in series in an electric circuit; the effect is additive. We can measure the surface temperature of each garment and of skin and atmosphere (Fig. 16) and calculate the insulating effect of each garment The insulating effect of the under-garment G_1 would be:

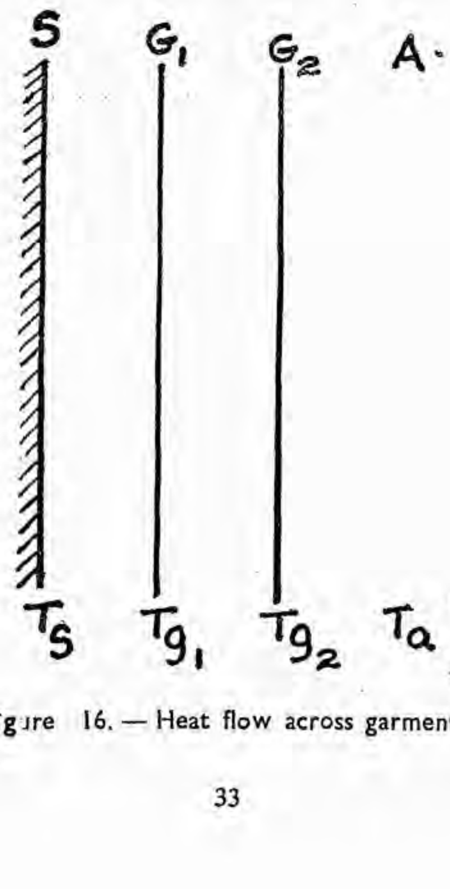


Figure 16. — Heat flow across garments

$$Ig_1 = \frac{T_s - T_{g1}}{T_s - T_a} \times 100$$

That of the over-garment G_2 :

$$Ig_2 = \frac{T_{g1} - T_{g2}}{T_s - T_a} \times 100$$

Table IX provides some figures for the insulation effect of the common

TABLE IX

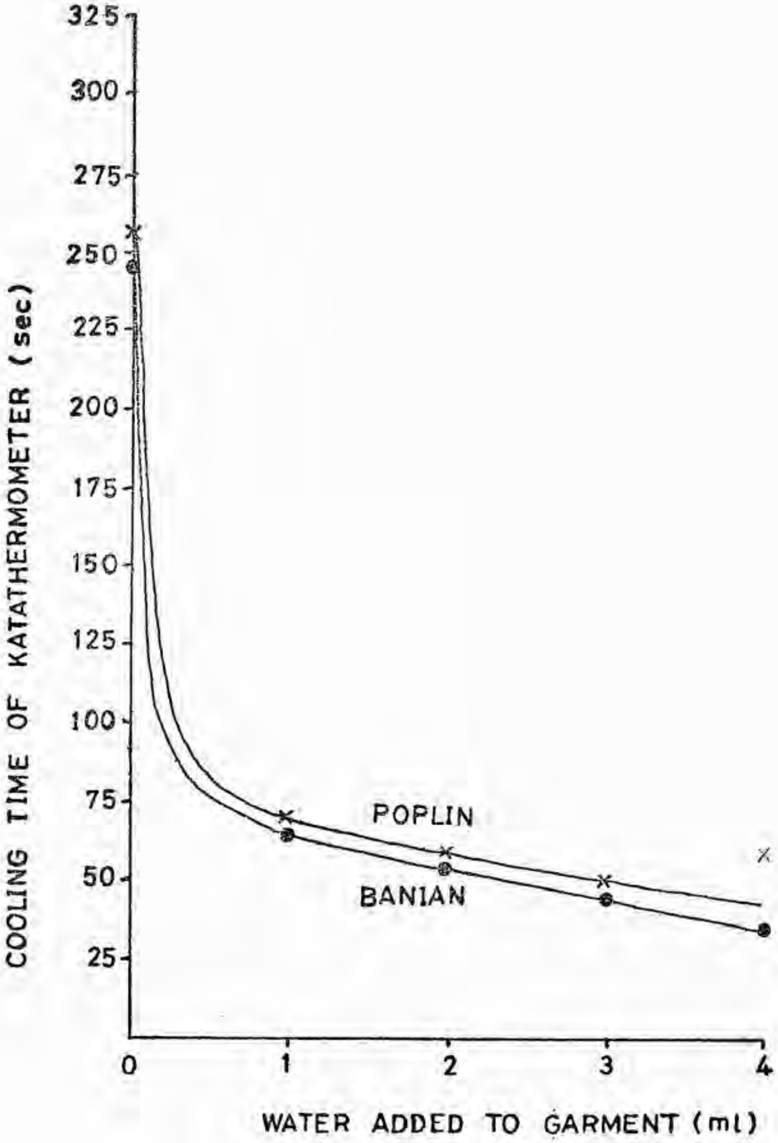
INSULATION EFFECT OF 2-LAYER AND 3-LAYER CLOTHING

Insulation effect (%)				
layer 1 (banian)	layer 2 (shirt)	layer 3 (outermost) garment)	Total 2 layer clothing	3 layer clothing
10	17	—	27	—
17	11	21 (overcoat)	—	49
3	21	5 (sweater)	—	29

two-layer clothing assembly of banian and shirt, and for three-layer clothing.

b) *Banian.* Does this mean that the banian is physiologically undesirable? This would seem to be so under non-sweating conditions. But what about sweating? Men tend to strip to the waist when working in the heat. There is, however, the possibility that a banian would absorb sweat and evaporate it faster than the naked skin can. Fig. 17 shows data with the katathermometer model regarding evaporation from wet banian material as compared with wet shirt material. Banian material is a better evaporator than shirt.

It is common experience that a banian is frequently wet with sweat while the shirt over it is dry. Hence it is likely to be the banian from which evaporation mostly occurs.



Banian a better evaporator than poplin. Clothed Katathermometer.

Figure 17

If a banian is a good evaporator, it would be a useful physiological crutch for heat loss under sweating conditions. We would like to know whether this theoretical possibility is actually realized under ordinary conditions. We do not know the answer to this problem. We might expect that a garment which throws an extra stress on the body would give rise to physiological strain. No doubt it would. The difficulty is to track down the strain and measure it. Indices such as body temperature, pulse rate, body weight loss (as an index of sweat loss) are too crude to be of any use for the present problem. Physiologists who have tried their hands at this have thrown them up in surprise and disappointment. Among the numerous studies done by the Tropical Climate Research Unit established by the British during World War II in Singapore were some on thermal comfort and on clothing. They could show no convincing evidence of physiological strain produced by garments which the wearers felt to be obviously thermally uncomfortable and unsuitable. In tests with three types of jungle uniform, no difference could be shown in terms of indices of physiological strain such as sweat loss, heart rate and body temperature, although one uniform was distinctly less comfortable than the other two.

Table X shows some results from the practical classroom. The question was whether the wearing of a banian is a physiological help or hindrance under sweating conditions. The 10 subjects did muscular

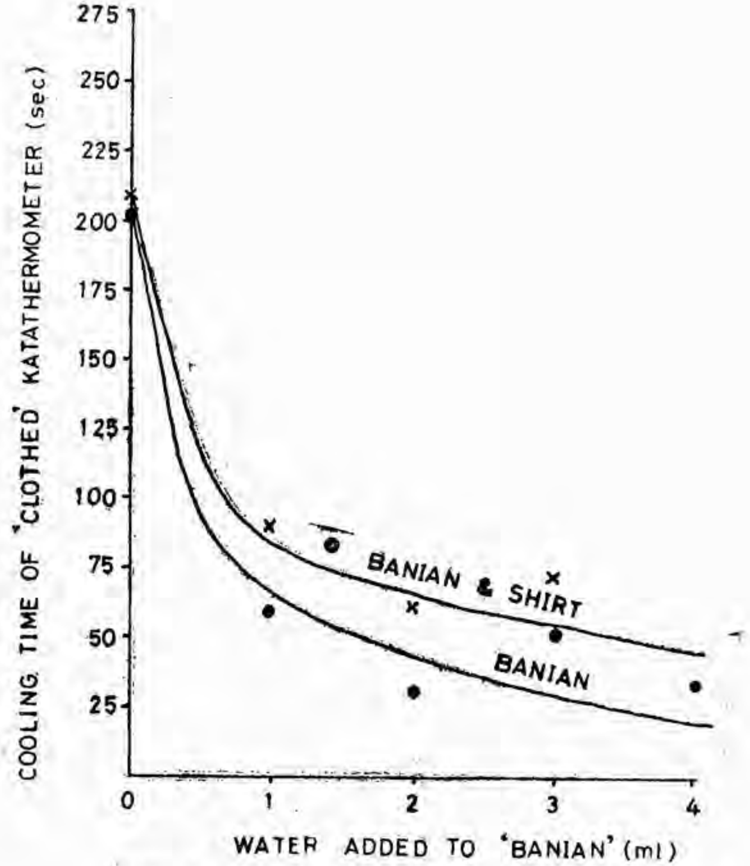
TABLE X

EFFECT OF WEARING A BANIAN UPON THE PHYSIOLOGICAL STRAIN IN MASCULAR EXERCISE (mean $\pm$ standard deviation)

Index of strain	No banian	Banian	Significance of the difference P
Heart rate (beats min)	137	142	<0.10 >0.05
Body weight loss (oz)	3.67	3.75	<0.10 >0.05

exercise on a bicycle ergometer and measurements were made of pulse rate and body weight loss. Each subject did the exercise (a) wearing a banian and (b) wearing no banian (bare-chested). Half the subjects did it with banian first and no banian second; the other half did it the other way round. The results suggest that the effect of a banian in muscular activity is on the whole a hindrance than a help, but the differences are not statistically significant.

c) *Evaporation from a wet banian covered by a shirt.* In the two-layer assembly of banian and shirt, the shirt not only imposes an additional barrier to heat outflow but also hinders evaporation from a wet banian. The idea is obvious but there are no human data to prove it. A katathermometer model can, however, be easily devised to show it. Fig. 18 shows the results of such an experiment.



Effect of a 'shirt' upon the evaporation of water from a wet 'banian' on a Katathermometer.

Figure 18

8.3.6 *Ventilation of the skin*

If air were visible we should see convective currents of warmed air rise under our garments and escape through the openings into the atmosphere. We should also be able to see the gusts of air that are blown over our skin by the bellows action of our garments during movement. Lacking such eyes we have to think of other ways of observing the ventilation of the skin. One way would be to place an odoriferous substance on the skin and find out whether the odour decreases by the action of air moving over the skin. If you paint the skin of both legs with equal amounts of an alcoholic solution of asafoetida (perungkayam) and then cover both patches with squares of cloth so that the trousers do not rub on the asafoetida; if you now exercise the right leg, keeping the left leg still as a control, you will find at the end of the exercise that the right leg has a distinctly weaker odour than the left. It is a nice little demonstration of the bellows action of trousers. Another way of demonstrating the bellows action of trousers and sarong would be to attach little wire cages to the legs; the wire cages contain a volatile substance broken off from a bathroom tablet of air freshener (paradichlorobenzene). The weight of substance before and after movement could be determined. This would give a quantitative measure of the bellows action of the garment. The results of such a study (Basnayake and Nicholas, 1978) showed that there was no significant difference between sarong and trousers, or between leg and thigh, with regard to the weight loss. The bellows effect appeared to be due to a wind created *in situ* under the garment rather than to a wind entering the garment from below.

Lee (1957) has remarked that "the thermal requirement for clothing (in warm humid environments) may be summed up in the phrase-there are no clothes like no clothes! Only by the maximum exposure of skin can ventilation be brought anywhere near optimum rates." "The first principle in the design of clothing for warm humid and wet environments is undoubtedly maximum ventilation of the space between clothing and skin, in order to facilitate evaporation. This is most easily obtained by a combination of minimum coverage, looseness of fit, absence of constrictions, and strategic placement of openings to promote through ventilation. In parts subjected to frequent bellows movement, small apertures in the clothing, such as those provided by mesh or net construction, may contribute importantly to this exchange. The second principle is maximum permeability to water vapour of the clothing over those parts inadequately ventilated, so that the accumulating vapour may pass without too much resistance to the exterior. The provision of a screen against direct solar radiation is necessary when that radiation is intense, but it is not required nearly so regularly as it is in hot dry environments. Light colours are similarly desirable where direct solar radiation is likely to be intense, but not necessary under many of the prevailing circumstances."

There is also the saying that 'in the tropics the naked child is the well dressed child.'

8.3.7 *Other factors affecting heat exchange via clothing.* A wet garment is a poorer insulator than a dry garment. Hall & Polte (1956) showed this quantitatively on a copper manikin dressed up in dry or wet clothing.

Chapter 9

SUMMARY

i. Attention is drawn to the overriding importance of psychological factors in the design of clothing.

ii. Physiological objectives in regard to clothing have been stated.

iii. Attention is drawn to the damage which shoes may produce on the feet.

iv. A method of estimating the heat insulating action of clothing was used. If a perfect insulator has a 100% effect, a shirt or a banian is about 10%; a shirt plus a banian about 20%; a shirt, banian and coat about 30 - 50%.

v. White fabrics are more effective than black in excluding radiant heat gain to the body from the environment. Black fabrics are possibly more effective than white in losing heat from the skin under ordinary room conditions.

vi. Shorts produce less physiological strain than overalls during muscular work in moderate heat. It is the other way round in severe heat.

vii. An attempt to estimate the usefulness of a banian in reducing physiological strain during muscular exercise did not give clear-cut results. They suggested, if anything, that a banian is a hindrance than a help during exercise.

viii. There is no significant difference between sarong and trousers in regard to the bellows action which they produce during movement.

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