

# Effect of Abaya Designs and Daily Wear Clothing on Thermal Comfort Measured with a Female Thermal Manikin

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## Abstract

Multiple layers of clothing are known to increase thermal resistance and evaporative resistance. This study investigates the effect of wearing abaya, an Islamic outerwear stipulated for women, on thermal resistance performance assessed with a female thermal manikin. Tests were conducted at two climatic conditions. The first set was at 23 °C and 50% RH as the dry condition and the second set was at 35 °C and 40% RH as the wet condition. Thermal resistance and evaporative resistance properties were measured by dressing a female thermal manikin in various ensembles of clothing within different types of abaya. The test results revealed that for all abaya combinations with daily wear, the manikin needed less heat to maintain the average skin temperature than with daily wear clothing alone. This study suggests that the abaya provided additional thermal and vapour resistance. Among the types of abaya evaluated, those worn on the head offered higher thermal resistance than those worn from the shoulder with tight sleeves. Marginal variations were also observed on the basis of the clothing worn under the abaya.

*Keywords:* Abaya Design; Thermal Resistance; Evaporative Resistance; Thermal Manikin; Clothing Comfort

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## 1 Introduction

Abaya is an outer garment for women particularly in the Islamic faith. It may be worn either from the shoulder or from the top of head over the normal day-to-day clothing (daily wear clothing). Abaya is normally used with a long scarf (Hijab) to wrap and drape over the head such that the neck and hair are completely covered. Considering the extreme climate in Saudi Arabia, with summer daytime temperature occasionally exceeding 45°C, wearing abaya can be very uncomfortable especially over several layers of clothing [1-3].

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Ease of body movement, tactile and thermal comfort are considered as components of clothing comfort. The type of fabric used and garment design are important to obtain good functional design and clothing comfort [4]. Celcar [5] defines clothing comfort as a state of mind influenced by a range of factors such as ambient temperature and relative humidity (RH), wind velocity, metabolism of wearer and most importantly the characteristics of the clothing worn. Therefore, clothing comfort may be considered to be the result of a balanced process of heat exchange between the human body, the clothing system and the environment. It may be quantified by the ability of the clothing to conduct heat and transport or restrict moisture from the surface of the human body to the environment, expressed as thermal resistance (thermal insulation) and water vapour resistance, respectively. It should be noted that factors such as colour, fashion, and the physical and psychological state of the wearer also influence the feeling of comfort. This paper reports thermal comfort only.

The type of clothing worn directly affects the heat loss from the human body to the environment. Clothing blocks conduction heat losses by trapping still air within the fabric structures and between garment layers. It resists convective losses by preventing convection heat current formation next to the body or by providing a barrier against air currents in the environment. Clothing also reduces radiant heat loss since the fibres in each fabric layer provide a thermal radiation barrier. Clothing impedes evaporative heat loss by restricting the evaporative of sweat that may be produced by the body [6].

Measurement of comfort has been commonly done through wearer trials, which are subjective [7, 8]. Recently thermal manikins were used to obtain objective results. With such manikins, the thermal resistance ( $R_{ct}$ ) and evaporative resistance ( $R_{et}$ ) of a clothing system can be determined [4, 5, 9]. The research with manikins has been primarily concerned for sportswear, sleeping bags and business attire usually under temperate or cold climatic conditions [10–19].

Al-Ajmi et al. [1] used both male and female thermal manikins to measure the thermal insulation and clothing area factors of a number of Arabian Gulf garments and ensembles for summer and winter seasons. Their study only provided data intended to be added to ISO 9920. To date no research has been carried out to understand the thermal comfort properties of abaya with a female manikin.

The aim of this study is to determine physical values related to the heat transfer properties of abaya ensembles as worn in Saudi Arabia by using a female sweating thermal manikin. The thermal resistance and evaporative resistance of clothing worn within the abaya were measured. The results could contribute to the improvement of abaya design so as to minimize thermal insulation and evaporative resistance in hot environment.

## 2 Materials and Methods

### 2.1 Materials

The inner garment (daily wear clothing) used in this study included Underwear (U), long Sleeve Shirt (SH) and Pants (P), and shoes. The outer garment (abaya and scarf combination) included three abaya designs: abaya worn from shoulder either with tight (TS) or Loose Sleeves (LS), and abaya worn from top of the head with tight sleeves (OH). The woven (WA) and knitted (KA) fabrics used for abaya were selected based on their comfort properties reported in previous studies

[2, 3]. Fig. 1 shows (a) Daily wear clothing (inner garment), (b) Abaya worn from shoulder with tight sleeves, (c) Abaya worn from shoulder with loose sleeves, and (d) Abaya worn from top of the head with tight sleeves. Every abaya along with a scarf (SC) (hijab) was worn in individual combination with daily wear clothing. The particulars of the clothing ensembles and abaya fabrics are presented in Table 1.

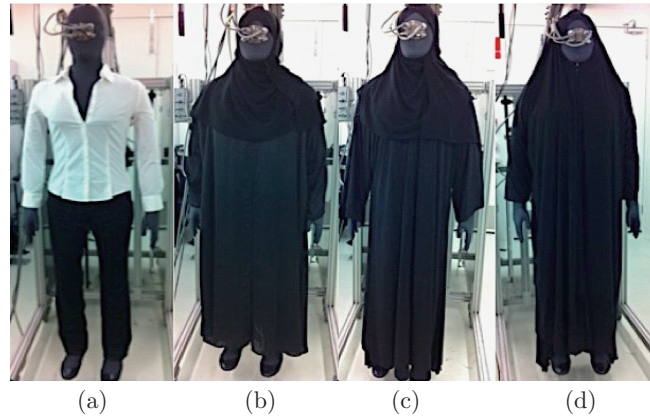


Fig. 1: Manikin dressing: (a) Daily wear clothing; (b), (c) and (d) Different abaya designs worn with scarf

Table 1: Fabric particulars of clothing ensembles

Clothing Code	Name	Fibre content	Mass per unit area (g/m <sup>2</sup> )	Thickness (mm)
U	Underwear	95% Cotton / 5% Elastane	170.0	0.64
SH	Long sleeve shirt	66% Cotton / 30% Polyester / 4 % Elastane	119.8	0.27
P	Pants	40% Cotton, 30% Viscose, 25% Polyester, and 5% Elastane	324.6	0.84
SC	Scarf	100% Polyester	69.4	0.22
WA	Woven fabric	100% Polyester	81.0	0.17
KA	Knitted fabric	96% Polyester, 4% Elastane	184.0	0.50

## 2.2 Methods

### 2.2.1 Sweating Thermal Manikin

A sweating thermal manikin of female form from MTNW, Seattle, USA was used to measure both thermal and evaporative resistance of clothing within various daily wear clothing and abaya combinations. The manikin is located in an environmental chamber where temperature, RH and wind speed can be controlled. This manikin is 1.70 m tall with a body surface area of  $1.8 \pm 0.3$  m<sup>2</sup>. It contains 20 independently controlled thermal zones. Fig. 2 shows the different zones of the manikin. All the thermal zones are fitted with heaters that simulate metabolic heat output rates and uses distributed wire sensors for measuring skin temperature. Additionally each thermal zone has sweat control through evenly distributed fluid ports on its surface. During the experiment,

the computer software (ThermDAC8) recorded the skin temperature and power requirement for each manikin zones as well as the surrounding temperature around the manikin.

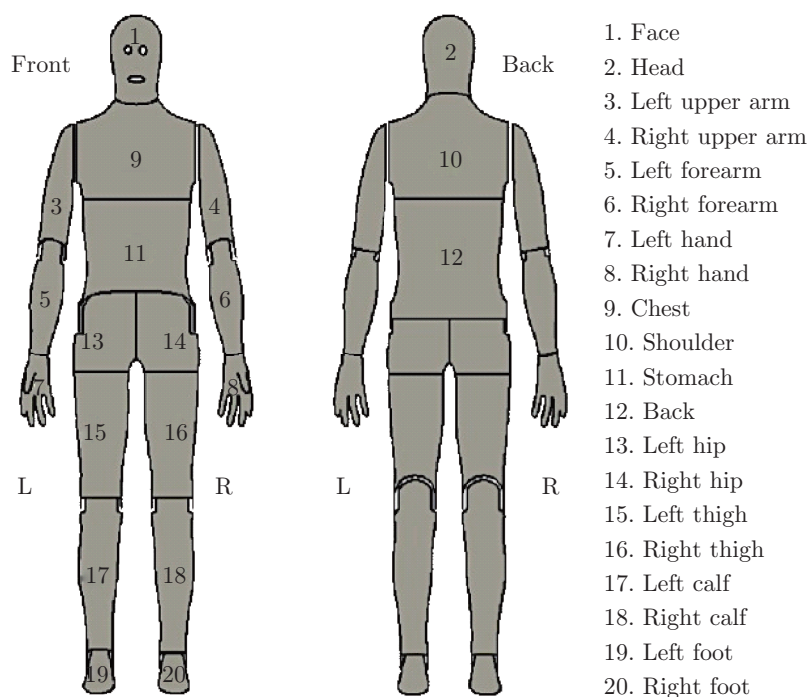


Fig. 2: Front and back views of sweating thermal manikin showing labelled zones

The mean skin temperature of the nude manikin was maintained at  $35 \pm 0.3$  °C and the air velocity in the manikin chamber was controlled at  $0.4 \pm 0.1$  m/s for both dry and wet test. For the dry condition, the manikin testing was done at 23 °C, 50% RH. The dry heat loss was measured for naked manikin. Then the manikin was clothed in underwear (bra and pantie). The readings from the manikin in underwear only were employed as the baseline reference for dry and wet tests. The average of triplicate tests was reported for each set of clothing samples.

In the wet conditions, the test was conducted in an isothermal condition and the manikin testing was done at 35 °C, 40% RH. In order to provide an evaporative surface, the sweating skin layer, which is on top of the heating layer and consists of a thin stretch cotton layer, was wetted before dressing. The skin suit was pre-wetted by spraying distilled water to simulate skin saturated with sweat. The manikin was automatically controlled by a computer system after testing parameters, including sweat setting, were entered through its interface. During the wet test, the total perspiration rate of the manikin was set to 440 mL/(hr · m<sup>2</sup>) to keep the surface of the manikin moist. The wet-naked manikin was allowed to evenly distribute the moisture over the skin to simulate skin saturated with sweat before the wet-tests. Measurements were taken for 45 minutes after the manikin was fully dressed. The 45 minute duration was set to allow sufficient time for the manikin within the abaya combination to reach steady-state condition and at maximum saturation in moisture absorption, if there is any.

In order to determine the effect of wearing abaya, tests were conducted by dressing the manikin in a base ensemble (U+P) followed by a test with the same ensemble in combination with an abaya. In the present study, the total thermal and evaporative resistance values for each ensemble was reported. Measurements were recorded in three discrete groups as shown in Fig. 3. They are:

- a) Head group – only the head without face,

- b) Torso group – chest, back and arms without hands,
- c) Lower torso group – hips and legs, and
- d) Abaya group – the entire manikin except face and hands.

All garments were preconditioned in the environmental chamber at the conditions they were to be tested for a minimum of 12 hours before testing, so that the manikin could stabilize more quickly.

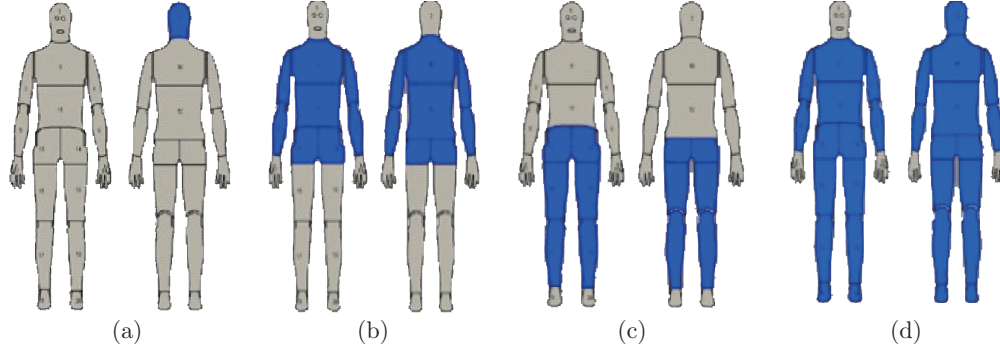


Fig. 3: Group for manikin testing results: (a) Head, (b) Torso, (c) Lower torso, and (d) Abaya (body fully covered with abaya)

### 2.2.2 Dry Thermal Resistance ( $R_{ct}$ )

The thermal resistance  $R_{ct}$  was measured according to ASTM F1291-10 – standard test method for measuring the thermal insulation of clothing using a heated manikin. The parallel method of calculating the total thermal resistance was used. The area weighted temperatures of all body segments were summed and averaged, the power levels to all body segments were summed, and the areas were summed before the total resistance was calculated using Eq. (1).

$$R_{ct} = (T_{skin} - T_{amb}) / (Q/A) \quad (1)$$

where,  $R_{ct}$  is the total thermal resistance (insulation) of the clothing ensemble and surface air layer ( $m^2 \cdot ^\circ C/W$ ),  $T_{skin}$  is the zone average temperature ( $^\circ C$ ),  $T_{amb}$  is the ambient temperature ( $^\circ C$ ), and  $Q/A$  is the area weighted Heat Flux ( $W/m^2$ ).

The intrinsic clothing insulation ( $R_{cf}$ ), defined as the insulation from the skin surface to the clothing surface, was deduced from the measured ( $R_{ct}$ ) value by Eq. (2):

$$R_{cf} = R_{ct} - (R_{ct0}/f_{cl}) \quad (2)$$

where,  $R_{cf}$  is the intrinsic evaporative resistance of clothing ( $m^2 \cdot ^\circ C/W$ ),  $R_{ct0}$  is the thermal resistance of air layer in naked condition ( $m^2 \cdot ^\circ C/W$ ) and  $f_{cl}$  is the clothing area factor (ratio of outer surface area of clothed body to surface area of nude body) estimated according to ISO Standard 9920 – Ergonomics of thermal environment – Estimation of thermal insulation and water vapour resistance of clothing ensemble.

### 2.2.3 Evaporative Resistance ( $R_{et}$ )

The evaporative resistance  $R_{et}$  was measured according to ASTM F 2370-10 – standard test method for measuring the evaporative resistance of clothing using a sweating manikin. The total evaporative resistance of the ensemble was calculated using Measurement Technology Northwest given by Eq. (3).

$$R_{et} = (P_{sat} - P_{amb})/Q/A - [(T_{skin} - T_{amb})/R_{ct}] \quad (3)$$

where,  $R_{et}$  is the total evaporative resistance ( $m^2 \text{ cotPa/W}$ ),  $P_{sat}$  is the saturation vapour pressure at skin temperature ( $m^2 \cdot \text{Pa/W}$ ),  $P_{amb}$  is the vapour pressure at ambient temp (Pa),  $Q/A$  is the area weighted Heat Flux ( $W/m^2$ ),  $T_{skin}$  is the zone average temperature ( $^{\circ}\text{C}$ ),  $T_{amb}$  is the ambient temperature ( $^{\circ}\text{C}$ ).  $[(T_{skin} - T_{amb})/R_{ct}]$  is the dry heat loss ( $W/m^2$ ), which is the heat flux under dry conditions.

Using the clothing factor, the intrinsic evaporative resistance of the clothing ensembles is given by Eq. (4).

$$R_{ef} = R_{et} - (R_{et0}/f_{cl}) \quad (4)$$

where,  $R_{ef}$  is the intrinsic evaporative resistance of clothing ( $m^2 \cdot \text{Pa/W}$ ),  $R_{et0}$  is the evaporative resistance of air layer in naked condition ( $m^2 \cdot \text{Pa/W}$ );  $f_{cl}$  is the clothing area factor estimated according to ISO Standard 9920.

## 3 Results and Discussion

The total thermal resistance and evaporative resistance within clothing of underwear and the manikin covered with clothing ensemble and different abaya combinations are plotted in Fig. 4 and Fig. 5.

### 3.1 Thermal Resistance

The thermal insulation values for the daily wear ensembles by themselves and abaya combination are plotted in Fig. 4. The coefficients of variation of repeated tests are generally less than 4%.

In Head group (Fig. 4) the abaya combination with daily wear clothing and abaya only had higher  $R_{ct}$  than the daily wear clothing by themselves. The reason was that the scarf was wrapped in two layers around the head while there was no scarf in daily wear clothing. The  $R_{ct}$  value ranged from  $0.12 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  on naked head to  $0.25 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  for the presence of scarf, which were within the scope of  $R_{ct}$  that has been reported in Pang et al. [16] the values of  $R_{ct}$  range from  $0.1 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  for the surface of a naked body (head) to  $0.2 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  for the helmet tested. In addition, Al-ajmi et al. [1] found that the  $R_{ct}$  values range between  $0.12 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  without covering the head to  $0.21 \text{ m}^2 \cdot ^{\circ}\text{C/W}$  for covering the head with scarf. Moreover, Mccullough et al. [20] reported that adding a hat to a relatively warm ensemble has a major effect on thermal insulation. Since the rest of the body is well insulated, much of the heat loss is from the head, and the hat blocks the heat loss. In addition, abaya worn on head had higher  $R_{ct}$  when compared to that worn from shoulder with tight or loose sleeves, because the former has three layers, two

from the scarf and the third one from abaya wearing top of the head. It is clear that woven fabric has, if not lower, similar thermal resistance compared to the knitted fabric in abaya only test and abaya combination test. This could be because woven fabrics are lightweight and thinner (Table 1), which results in slightly lower  $R_{ct}$  compared with knitted fabrics.

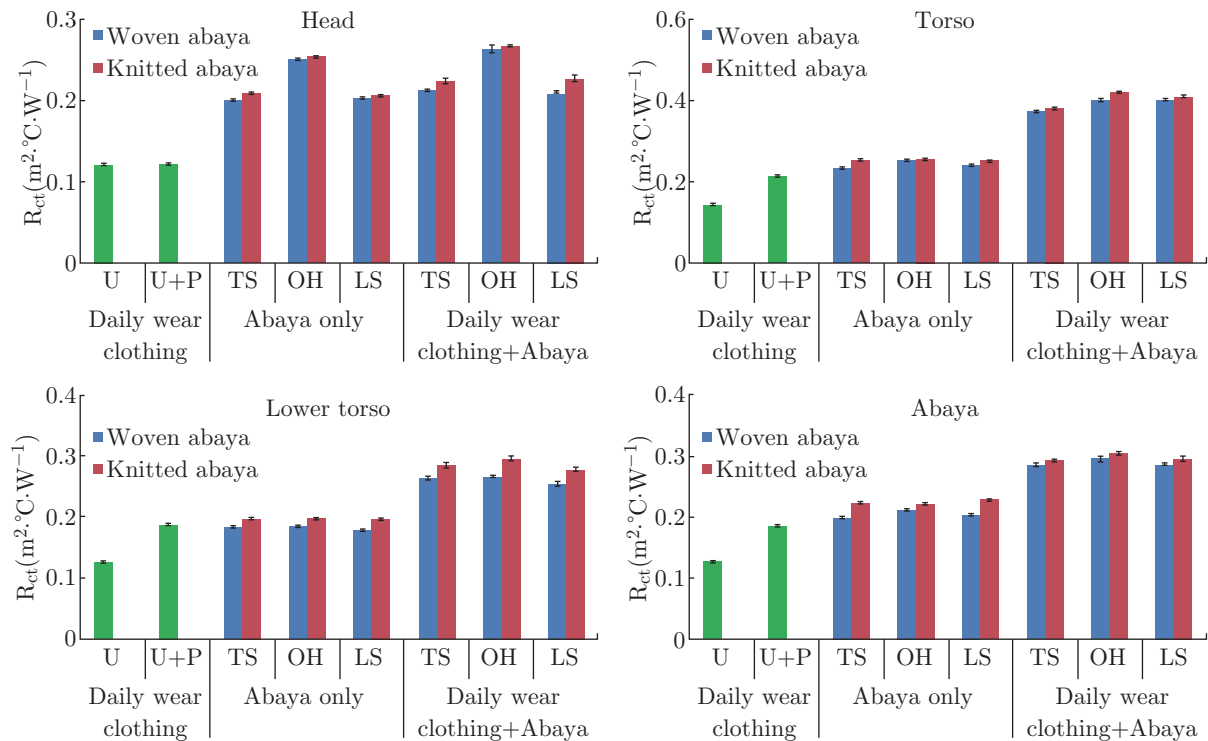


Fig. 4: Thermal resistance values of daily wear clothing, abaya only and daily wear clothing with different designs of woven and knitted abaya in Head, Torso, Lower torso and Abaya groups

In Torso group (Fig. 4), the abaya combination with pants shows higher  $R_{ct}$  compared to abaya only. This could be because they have three layers or more in some part of the body especially in chest area (bra, shirt, abaya and scarf). In addition, the thickness of the underwear was higher than the shirt and woven abaya (Table 1). Chest and the upper part of the back are the areas of the body that tend to touch by clothing. Since garments block the air ventilation between the garment and the body [21], the multilayers in chest area create high thermal resistance, hence more heat stress. In addition, more layers create additional pockets of still air resulting in high thermal insulation compared to single layer fabric [22]. As suggested by McCullough [6], adding clothing to a particular area of the body will reduce the heat loss only from that area and will have no effect on the other areas. Therefore, the Torso group shows generally higher  $R_{ct}$  than other groups. In this Torso group, abaya only shows slightly lower  $R_{ct}$  than the clothing combination. This could be because shirt and abaya is shaped to fit loosely in the chest area, which creates a small air gap, which could be related to the convex body geometry [23]. This may mean that the natural convection exists even within the smallest air gaps because of the standing position of the manikin [24]. Moreover, when fabric was made into clothing, the air gaps between the skin and clothing influenced the thermal insulation more than the intrinsic thermal insulation of the fabric as reported by Li [8]. From this point of view, the fabric selection for abaya seems less important than abaya design.

In Lower torso group (Fig. 4), abaya combination with pants presented higher  $R_{ct}$  compared

with abaya only and daily wear clothing. This could be because the thickness of pants was higher compared to woven and knitted abaya fabrics (Table 1), though pants were held tight to the thigh and thereby high radiation loss. McCullough et al. [20] investigated how garment design influences the thermal insulation value of clothing. By comparing tight-fit and relatively loose-fit long trousers, they found that loose-fit trousers provided higher insulation than tight fit trousers (0.34 clo and 0.24 clo respectively). In addition, lower torso (hip, thigh and calf) shows larger air gap in abaya combination because abaya create more air gap. This study is similar to that reported by Lu et al. [23], who found that air gap unevenly distributed over the body surface. In this study, larger size of air gap was observed in legs and abdomen. The air gap of convex area was smaller than that of concave area. An increase of garment size will increase the air gap, hence abaya size could be considered to manage thermal comfort.

In Abaya group (Fig. 4), when comparing the design and fabrics for abaya, wearing abaya on head shows slightly higher  $R_{ct}$  than wearing abaya from shoulder with tight and loose sleeves. This is again due to more layers on head than the abaya worn from shoulder. Furthermore, abaya made from knitted fabric also show slightly higher  $R_{ct}$  than that made from woven fabrics. The structure of the fabric in woven was satin weave and thin (thickness 0.17 mm), which allowed more air and heat pass through the fabrics. The woven fabric also had lower  $R_{ct}$  ( $0.0005 \text{ m}^2 \cdot ^\circ\text{C}/\text{W}$ ) according to the previous study [2]. In addition, the  $R_{ct}$  of knitted fabric was high ( $0.0075 \text{ m}^2 \cdot ^\circ\text{C}/\text{W}$ ) [3]. The knitted fabric (single jersey) was also thicker (0.8 mm) than the woven fabric (0.17 mm). Moreover, an abaya covers about 86% of the body surface area, scarf or Hijab about 12%, when comparing with the daily wear which covers only 82% according to ISO 9920. When fabric was made into clothing, the thermal insulation was influenced more by the air gaps between the skin and clothing than by the intrinsic thermal insulation of the fabric [8]. In this context, abaya creates large air gaps, which provide more insulation. Therefore, abaya contributes a significant amount of thermal insulation.

### 3.2 Evaporative Resistance

The evaporative resistance values for the daily wear ensembles by themselves and abaya combination are plotted in Fig. 5. The coefficients of variation of repeated tests are generally less than 4%.

The evaporative resistance in Head group in Fig. 5 shows that the daily wear clothing had similar  $R_{et}$  value. This is because the head was not covered with scarf. However, the head start to have a higher  $R_{et}$  values when only abaya and abaya with daily wear clothing were presented. This indicates that abaya may create a high level of heat stress because heat stress is directly related to the value of evaporative resistance [16]. In addition, the  $R_{et}$  values when wearing abaya from top of the head in knitted and woven fabrics are higher than that when wearing abaya from shoulder with tight or loose sleeves. In terms of fabrics, abaya knitted fabric had higher  $R_{et}$  than the woven fabric. In the previous studies [2, 3] the knitted fabric had higher  $R_{et}$  ( $1.86 \text{ m}^2 \cdot \text{Pa}/\text{W}$ ) than the woven fabric ( $0.67 \text{ m}^2 \cdot \text{Pa}/\text{W}$ ). Therefore, knitted abaya tended insulating more than woven abaya.

In Torso group in Fig. 5, the daily wear clothing show lower  $R_{et}$  value compared with abaya combination. The main reason for this difference between  $R_{et}$  values in daily wear clothing and abaya combination was that daily wear clothing has two layers, one was shirt and the other was bra. Moreover, both clothing (underwear and shirt) had higher content of cotton (being very



hygroscopic), which absorbed more moisture as every day clothing worn in normal wear when comparing to polyester fabrics which has very poor moisture absorbing capability. In contrast, abaya combination had more layers, which are bra, shirt, abaya and some part of the scarf covering the chest area. Abaya alone has slightly higher  $R_{et}$  values than the daily wear even though the daily wear clothing has two layers. In addition, abaya alone had one layer and some part of the scarf covered the chest area. As a result, air gaps were large due to the drape of the fabric, which hung the fabric away from the body and slowed the moisture evaporation through the fabric to the environment.

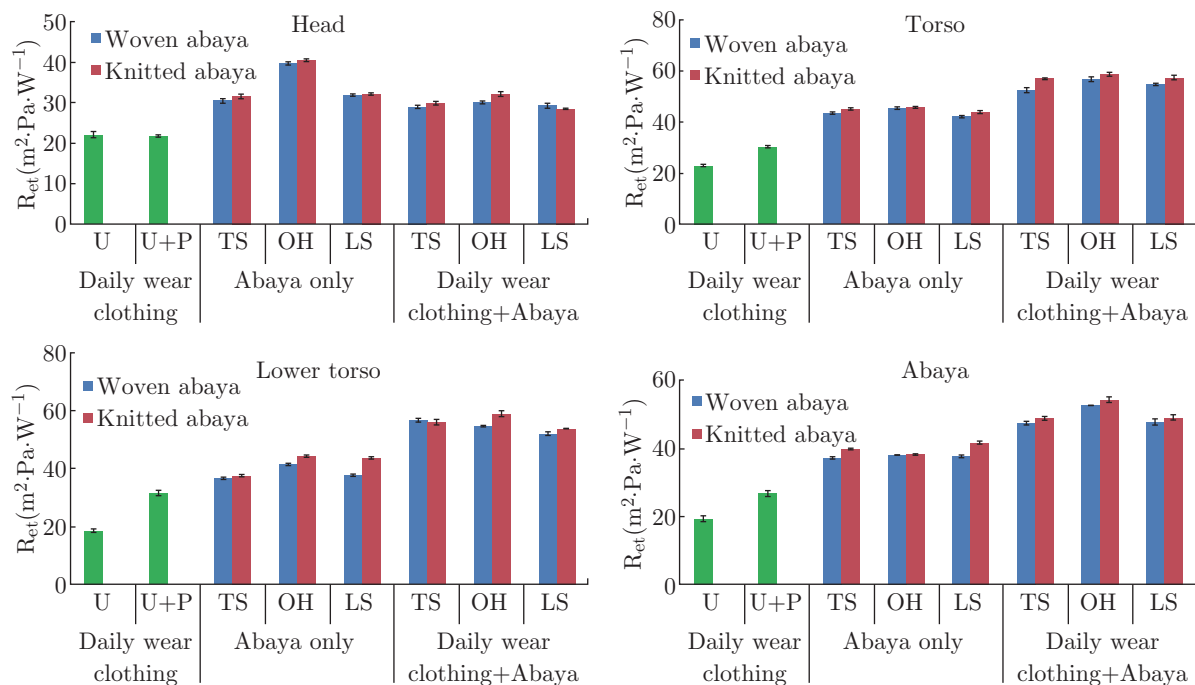


Fig. 5: Evaporative resistance value of daily wear clothing and daily wear garments (pants with shirt) with different designs of woven and knitted abaya in Head, Torso, Lower torso and Abaya groups

In Lower torso in Fig. 5, the pants ensemble and pants with abaya combination had higher  $R_{et}$  and intrinsic evaporative resistance values than the pants ensemble and abaya only. This could be because the pants were held to the thigh and thereby lower radiation loss. Air layers also create resistance to diffusion of evaporated sweat to the environment, which is proportional to the thickness of clothing ensemble. For fabrics, the vapour resistance is dependent on the enclosed air and the density of the construction [25]. Tight fitting minimizes air circulation between skin and clothing. Also, because the pants wear next to skin, they absorbed more moisture and have higher content of cotton (being very hygroscopic) (Table 1). Therefore, pants had lower  $R_{et}$  and  $R_{ef}$ .

In Abaya group in Fig. 5, wearing abaya from top of the head in woven or knitted fabrics shows higher  $R_{et}$  values as well. As discussed earlier, this could be because abaya on head had three layers – two layers were from scarf when wrapped to the head and the third layer was abaya. Moreover, the results show that knitted fabrics had higher  $R_{et}$  values than woven fabrics. This is due to that knitted fabric has a higher  $R_{et}$  values than woven fabric.

Overall, based on the fabric used in this study, abaya combination in woven fabric seems to be more comfortable than the knitted abaya combination. This agrees with the survey conducted

by the authors, whose findings are that 67% of women prefer to wear woven abaya than knitted abaya. In terms of design, wearing abaya in shoulder with tight or loose sleeve appears to be more comfortable than wearing abaya on the top of head.

## 4 Conclusion

Three designs of abaya, each made from two types of fabric, in combination with daily wear clothing (underwear, pants and shirt) were investigated for thermal comfort utilising a female sweating thermal manikin. Among the types of abaya evaluated, those worn on the head (produced from either woven or knitted fabrics) offered slightly higher thermal and evaporative resistance than those worn from the shoulder with tight or loose sleeves. The thermal and evaporative resistance in abaya combination was higher than that for daily wear clothing ensemble itself, or abaya alone. In other words abaya contributes a significant amount of thermal insulation and evaporative resistance, which would lead to heat stress in a hot environment. Abaya creates large air gaps between the skin and abaya, which resist body heat transfer and moisture evaporation through abaya fabric. As a result, the intrinsic thermal properties of abaya fabrics affect less on the overall thermal comfort performance of multiple layers of clothing. The trend is that abaya made from woven fabric may be more comfortable as measured by thermal resistance and evaporative resistance than the abaya made from knitted fabric.

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