THE COMFORT, MEASURED BY MEANS OF A SWEATING MANIKIN (WALTER^{TM}), OF CLOTHING CONTAINING DIFFERENT FIBRE COMBINATIONS: A PRELIMINARY INVESTIGATION

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ABSTRACT

With the growing importance of clothing comfort in South African and overseas markets for locally produced clothing, the Council for Scientific Industrial Research (CSIR) acquired an advanced sweating fabric manikin for measuring clothing comfort. This preliminary investigation covers the comfort related properties, as measured by means of the Sweating Manikin (Walter^{TM}), of six local clothing ensembles (worsted suit, shirt and underwear) containing different fibre combinations. Although the clothing ensembles, comprising suits with the different fibre combinations, differed somewhat in terms of their comfort related properties, namely thermal resistance, water vapour resistance and moisture permeability index, the differences tended to be neither consistent nor large, and appeared to be related to differences in the fabric structural parameters. Nevertheless, the ensembles comprising the different underwear, namely cotton or wool/nylon, differed consistently, with the thermal and water vapour resistance generally higher, and moisture permeability index generally lower for the ensembles with the wool/nylon underwear than for those with the cotton underwear. Further work, covering a wider range of fabrics and fibre types, is in progress to verify the findings of this preliminary study.

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INTRODUCTION

Comfort is an important consideration when selecting clothing to purchase or wear, the requirements varying greatly depending upon the environment under which the clothing will be worn and the level of physical activity, specific characteristics, requirements and preferences of the wearer. Clothing comfort is of particular importance in South Africa, with its hot, often humid, summers and cold, often wet, winters. Nevertheless, except for fabric feel and weight/ thickness, it is generally very difficult for a South African consumer to assess the potential comfort in wear of a particular garment. Mostly they have to rely either on their own experience or on fibre and brand related information in the public domain and these may be unreliable for various reasons. This is further complicated by the fact that garments are rarely worn singly or in single layers, rather are they worn in various combinations i.e. as ensembles. For example, in the case of men's office, or formal wear, the ensemble often consists of a suit worn with a shirt (and tie), underwear and socks. It is with the above in mind that the Council for Scientific Industrial Research (CSIR) in 1996 acquired one of the most advanced manikins, a sweating fabric manikin (Walter^{TM}), to enable it to measure the comfort related properties of clothing produced in South Africa and also those imported.

Because of the importance of clothing comfort, much research has been carried out in which the comfort related properties, notably thermal resistance and water vapour resistance, of fabrics have been measured by means of instruments designed specifically for this purpose. The results so generated were then used, either individually or combined, to arrive at an overall fabric comfort measure or index, for example, moisture permeability index. Before the development of the first thermal manikin, measurement of the comfort related properties of textiles and clothing was confined to fabrics, as opposed to garments and garment ensembles. With the development of modern thermal manikins (Goldman (2006)), it has become possible to measure individual items of clothing as well as layers of clothing, under conditions simulating those experienced during actual wear. Ten years ago there were already well over 100 thermal manikins in place globally (Fan, 2006). One of the major developments in this field is that of Walter™ (Figure 1), a sweating fabric manikin covered by a breathable fabric skin, developed by the Hong Kong Polytechnic University in 2001, which could simulate human walking motions and perspiration, using temperature controlled water (37°C) and breathable fabric (Fan and Chen, 2002; Fan and Qian, 2004). Different kinds of breathable fabric can be used to simulate different rates of perspiration. According to Qian (2005) and Starr (2010) the most crucial parameters tested by the manikin are thermal insulation and water vapour resistance.

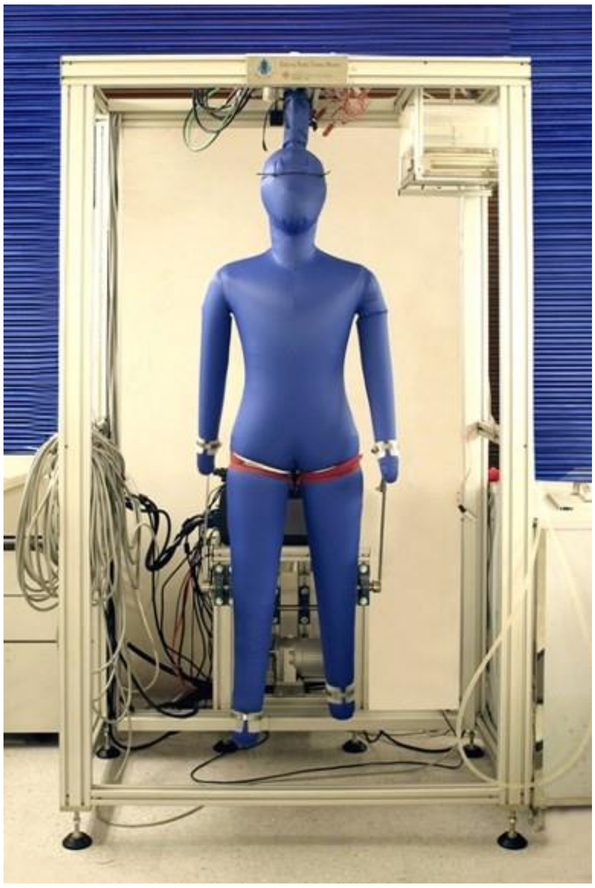

FIGURE 1: WALTER™ THE FABRIC SWEATING MANIKIN (SOURCE: FAN, NO DATE)

One of the questions which often arise, concerns the relative merits, in terms of comfort, of different types of fibres or fibre combinations, e.g. natural or man-made. Various studies have, in fact, compared the comfort related properties, notably thermal insulation, of underwear and apparel fabrics containing different types of fibres, both natural and man-made, these having been reviewed by Marsh (1931), Morris (1953), Slater (1977), Ukponmwan (1993) and others. Although contradictory results sometimes were reported in the different studies, the majority, by far, found that fabric thermal resistance was largely related to the fabric thickness, more specifically the volume of air entrapped in the fabric, with fibre type (i.e. fibre substance) apparently playing a relatively minor role. For example, Speakman and Chamberlain (1930) concluded that, at the same fabric weight and thickness, wool fabrics were better thermal insulators than the fabrics composed of the other fibres which they tested, whereas, Baxter and Cassie (1943) showed that, for a range of fabrics differing widely in fibre composition and thickness, fabric thermal resistance was mainly related to fabric thickness, rather than fibre type or composition. Many similar or related studies on fabric thermal resistance have been carried out (Rees (1946), Cassie (1946), Holcombe and Hoschke (1983), Peirce and Rees (1946), Yoon and Buckley (1984), Holcombe (1984), Tyagi *et al* (2004), Das *et al* (2009), Gericke and Van Der Pol (2010), and Stoffberg *et al* (2015)). By far the majority of the researchers found fabric thermal resistance to be almost linearly related to fabric thickness (fabric density constant), with fibre type or composition having only a relatively small effect, if any, on fabric thermal resistance.

Various studies have been carried out over the years on the water vapour resistance of fabrics of different fibre compositions, these including those by Peirce *et al* (1945), Mehta (1984), Tyagi *et al* (2004), Yoon and Buckley (1984), Kothari (2006), Mazzuchetti *et al* (2007), Das *et al* (2009) Lee and Obendorf (2012), Gericke and Van Der Pol (2010) and Stoffberg *et al* (2015). As in the case of fabric thermal resistance, different researchers sometimes reported contradictory results, particularly with respect to the role and importance of fibre type or hygroscopicity, in determining fabric water vapour resistance. For example, Peirce *et al* (1945 and also in Shirley Institute Memoirs, 1945, V, 51, as quoted by Rees 1946) found that the water vapour resistance of fabrics, differing in fibre composition, tended to increase almost linearly with increasing fabric thickness or decreasing fabric density, with fibre type having little apparent effect. Similar results were reported by Mehta (1984) on underwear, Mazzuchetti *et al* (2007) on non-woven fabrics, Demiryürek and Uysaltürk (2013) on Viloft/ polyester knitted fabrics and by Stoffberg *et al* (2015), on commercial woven fabrics concerning the small, or even lack of, fibre type effect on fabric water vapour transmission or resistance. In contrast to this, Yoon and Buckley (1984), Kothari (2006), Das et al (2009) and Lee and Obendorf (2012) found that fibre type played a role in fabric water vapour transmission. Nevertheless, it is possible that these researchers had not considered changes in fabric structural and other parameters which may have been associated with the various fibre types, and which, rather than fibre type, may have been responsible for the effects attributed to fibre type. As early as 1931 Marsh pointed out the dangers of comparing the thermal properties of different fibres *per se* (different fibre substances) when in fabric form, due to the differences in fabric structural properties, notably thickness and density, which influence air entrapment and movement, and therefore the comfort related properties associated with different fibres, even if fabric mass and weave structure are the same. Similar considerations apply to water vapour resistance.

Although the effects of clothing design and style (Fan, 2009, Fan and Tsang (2008), Mehta and Harnett, 1981 and Chen *et al* 2004) and different clothing ensembles (Holcombe 1984, Ho *et al* 2011, Keighley, 1985 and Fan and Chen 2002) on comfort related properties of clothing have been investigated, using a thermal sweating manikin, relatively little research using a thermal manikin, such as Walter^{TM}, appears to have been done specifically on clothing or clothing ensembles which contain different fibre types or fibre combinations. Gericke and Van der Pol (2010), compared the comfort related properties, as measured on Walter™, of T-shirts made from cotton, regenerated bamboo and viscose rayon, respectively, and found no statistically significant differences between the three T-shirts, concluding that there was no evidence that bamboo was superior to either cotton or viscose rayon according to their results. Fonseca (1970), using a heated ‘sweating sectional manikin’, postulated that the outerwear could be the deciding factor in determining the thermal characteristics of complete clothing ensembles involving different fibre combinations.

In light of the above, and with the growing importance of clothing comfort worldwide, a project using Walter^{TM}, a fabric sweating

TABLE 1: DETAILS OF FABRICS USED FOR SUITS, SHIRTS AND UNDERWEAR, RESPECTIVELY

Code	Fabric Composition	Mass (g/m²)	Thickness (mm)	Density (kg/m³)**	Air permeability (cm³/s/cm²)	Fabric Structure
Suit 1	100% polyester*	158	0,48	329	62,3	1x1 Plain Weave
Suit 2	52/48% wool polyester*	156	0,27	578	27,5	1x1 Plain Weave
Suit 3	100% wool*	162	0,26	623	24,1	1x1 Plain Weave
Lining	100% polyester	63	0,07	900	28,8	1x1 Plain Weave
Shirt	100% cotton	118	0,24	492	17,5	1x1 Plain Weave
Underwear 1	100% cotton	200	0,94	213	86,3	1x1 Rib Knit
Underwear 2	80/20% wool/nylon	180	1,09	165	97,9	1x1 Rib Knit

*Excluding suit jacket lining
**Derived from the fabric mass and thickness

manikin, was initiated on the comfort related properties of different clothing ensembles involving typical local men's suits containing different fibre types. A sweating manikin was to be used in preference to the more common and traditional tests on fabrics, since it far more closely simulates wear conditions by enabling clothing ensembles, more typical of real life conditions, to be tested and evaluated. The preliminary results, covering six different clothing ensembles, are reported in this paper.

EXPERIMENTAL

Materials and fabric testing

Three commercial 1x1 plain weave worsted woven suiting fabrics (see Table 1) of similar mass (159g/m^2 ± 2.5%), but of different fibre compositions, were sourced from a local commercial clothing manufacturer, these being considered fairly typical for men's suits worn in South Africa. The compositions of the three suiting fabrics were 100% wool, 100% polyester and 52/48% wool/polyester, respectively. The fabrics were conditioned under standard atmospheric conditions of 21°C (±2°C) and 65% (±2%) humidity for 24 hours before being tested for fabric mass according to SANS 79:2004, and thickness according to ISO 5084: 1996, three specimens being measured to determine the average fabric mass (g/m²) and 10 specimens to obtain the fabric air permeability.

Three identical men's suits, of a design and style typical of men's worsted suits in South Africa, were manufactured from the above mentioned suiting fabrics, using the same 100% polyester lining in each jacket of the suit. In addition, two commercial underwear garment sets (vest and long john), produced from 1x1 rib knitted fabric, comprising different fibre compositions (100% cotton and 80/20% wool/ nylon blend, respectively), were sourced from a clothing manufacturer, relevant fabric details being given in Table 1.

Clothing ensembles, comprising each of the three suiting fabrics with each of the two underwear garment sets, were prepared, giving a total of six clothing ensembles in all. The six clothing ensembles (see Table 2), involving the different combinations of the suits and underwear, but the same 100% cotton long sleeve shirt, were tested on Walter™ as detailed below, and three suits are shown on Walter in Figure 2.

TABLE 2: RESULTS OF TESTS CARRIED OUT ON CLOTHING ENSEMBLES ON SWEATING MANIKIN (WALTER™)

Ensemble Code	Suit Code	Suit Fabric Composition*	R_{et} (m²Pa/W)	R_t (m²C/W)	MP Index (I_m)	Under Wear
A	Suit 1	100% polyester	40,7	0,213	0,317	**100% Cotton**
B	Suit 2	52/48% wool/ polyester	39,0	0,200	0,310	
C	Suit 3	100% wool	40,2	0,196	0,296	
D	Suit 1	100% polyester	43,3	0,211	0,295	**80/20 Wool/Nylon**
E	Suit 2	52/48% wool/ polyester	43,3	0,207	0,290	
F	Suit 3	100% wool	45,3	0,211	0,282	

*Excluding suit jacket lining
R_{et} = Water Vapour Resistance
R_t = Thermal Resistance
MP Index = Moisture Permeability Index (I_m)

Walter™ test and interpretation of measurements

Tests: The tests on Walter™ were carried out in accordance with ISO 15831:2004, as described by Fan and Chen (2002) at a room temperature of 20°C, Relative Humidity of 50%, an air velocity of 1m/s and a core temperature of

FIGURE 2: WALTER™, THE FABRIC SWEATING MANIKIN, DRESSED IN THREE DIFFERENT SUITS

37°C.

Calculation: According to Fan and Chen (2002), thermal insulation and water vapour resistance are calculated by measuring the heat supply to the manikin, the temperature at the skin, the temperature and humidity of the environment, as well as the perspiration rate of the manikin. Walter™ uses special software to determine the thermal insulation R_t and moisture vapour resistance R_{et} of the clothing being tested (Anon, n.d. and Fan and Chen, 2002).

The thermal insulation (R_t), calculated by the Walter™ software, is in ISO units, i.e. $m^2\ {}^oC/W$, and can be converted to other units (Clo and Tog) using the following convertions:

$$1 \text{ Clo} = 0.155 \ m^2\ {}^oC/W$$
$$1 \text{ Tog} = 0.1 \ m^2\ {}^oC/W$$

From the thermal insulation (R_t) in $m^2\ {}^oC/W$ and moisture vapour resistance (R_{et}) in $m^2 P_a/W$, one can calculate the moisture permeability index, I_m, by using the following formula (ISO9920):

$$I_m = 60.6 \times \frac{R_t}{R_{et}}$$

The moisture permeability index I_m is dimensionless, and changes the concept that clothing should keep the wearer warm to one that clothing should maintain a level of thermal equilibrium (Woodcock, 1962, Anon, n.d., Fan, n.d. and Fan and Chen, 2002).

Interpretation of Values (Anon, n.d. and Fan and Chen, 2002): The thermal resistance or insulation, R_t, should be as low as possible for summer clothing to keep one cool;

The thermal resistance or insulation, R_t, should be as high as possible for winter clothing to keep one warm;

The water vapour resistance, R_{et}, of clothing should be as low as possible for any type of clothing to make the clothing permeable;

The moisture permeability index, I_m, should be as high as possible (maximum 1) for any type of clothing to make the clothing permeable;

RESULTS AND DISCUSSION

Effects of fabric structural parameters

As already mentioned in the Introduction, it has generally been found that, within practical limits, fabric thermal resistance increases almost linearly with fabric thickness, and decreases with an increase in fabric density, or a decrease in porosity, these effects being largely related to the amount of air entrapped in the fabric. For example, in a recent study (Stoffberg *et al* 2015), covering some 26 commercial worsted fabrics, varying in mass, thickness and fibre composition, it was found that both fabric water vapour resistance (R_{et}) and thermal resistance (R_t) increased with an increase in fabric mass and thickness, and with a decrease in fabric density, with the moisture permeability index (I_m) tending to increase with a decrease in fabric mass, and with an increase in fabric airpermeability and thickness, fibre type apparently only playing a relatively minor role, if any at all.

In the light of earlier findings, and based upon the main findings/relationships obtained by Stoffberg *et al.* (2015), the clothing ensemble thermal resistance (R_t) results obtained here have been plotted against the suiting fabric thickness (Figure 3), while the clothing ensemble water vapour resistance (R_{et}) has been plotted against suiting fabric mass (Figure 4). The clothing moisture permeability index (I_m) has been plotted against suiting fabric thickness (Figure 5) and density (Figure 6), respectively, with the suiting fabric blend and underwear composition being indicated by different points in Figures 3 to 6. Superimposed on the figures, are the associated linear regression equations and lines as well as correlation coefficients (R^2 x 100).

What is immediately obvious from Figures 3 to 6, is that the underwear (i.e. wool/nylon *versus* cotton) generally had a greater and more consistent effect than suiting fabric blend, on all the comfort related properties, with the clothing ensembles comprising the cotton underwear generally having lower thermal (R_t) and water vapour (R_{et}) resistances, and a higher moisture permeability index (I_m) than those of the ensembles containing the wool/nylon underwear, possibly due to the lower thickness and greater density, and associated lower volume of air entrapped, of the cotton underwear fabric.

Figures 3 to 6 also show that, as found previously by Stoffberg *et al.,* (2015), the clothing ensemble thermal resistance (R_t) tended to increase with the suiting fabric thickness, and the water vapour resistance (R_{et}) with an increase in suiting fabric mass, irrespective of the underwear composition. Furthermore, as also found by other workers on fabrics, the clothing ensemble moisture permeability index (I_m) decreased with an increase in suiting fabric density and with a decrease in suiting fabric thickness. The much greater thickness and lower density of the 100% polyester fabric are probably due to a higher fibre and yarn bulk and crimpiness, which in turn will result in a greater air entrapment within this suiting fabric and therefore also within the ensemble, explaining the higher thermal resistance of this particular suiting ensemble, and possibly also the reason for the smaller effect of underwear type in this particular case.

Effect of suiting fabric blend

Although the three suiting fabrics were the same weave and of similar mass (159g/m^2±2%), the association between blend level and certain fabric parameters, notably thickness, clearly complicated isolating the effect of blend level *per se* on the various comfort related properties of the clothing ensembles. Nevertheless, if the

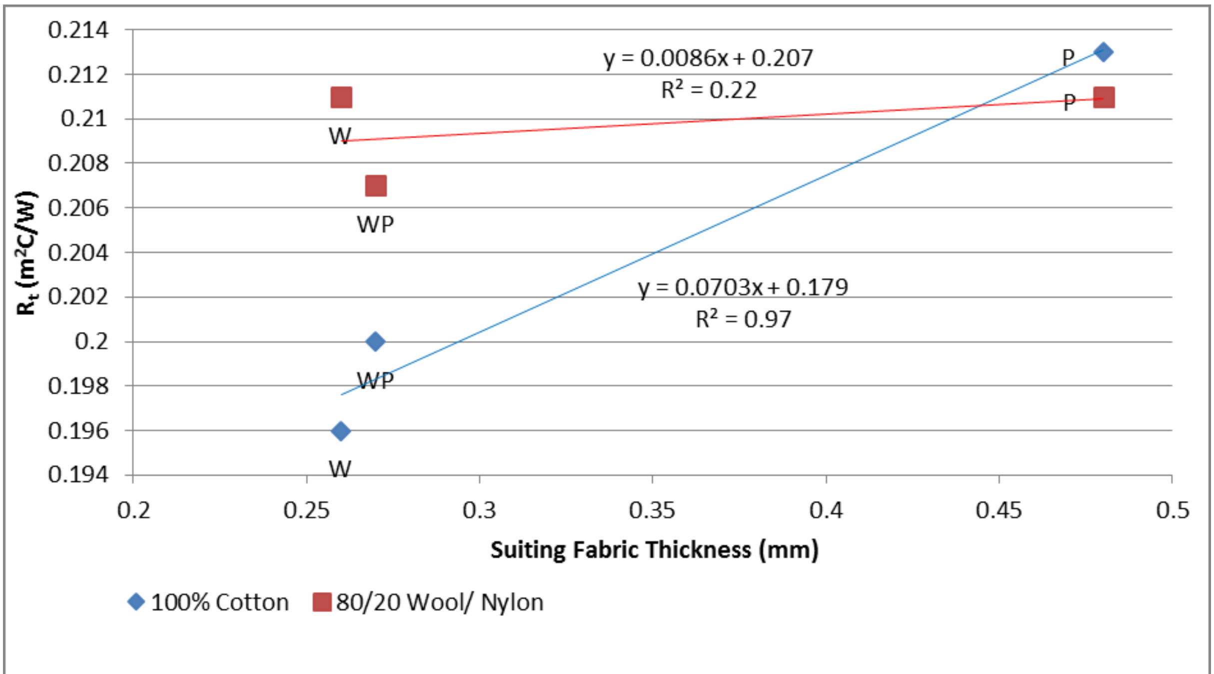

FIGURE 3: CLOTHING ENSEMBLE THERMAL RESISTANCE (R_t) *VS* SUITING FABRIC THICKNESS

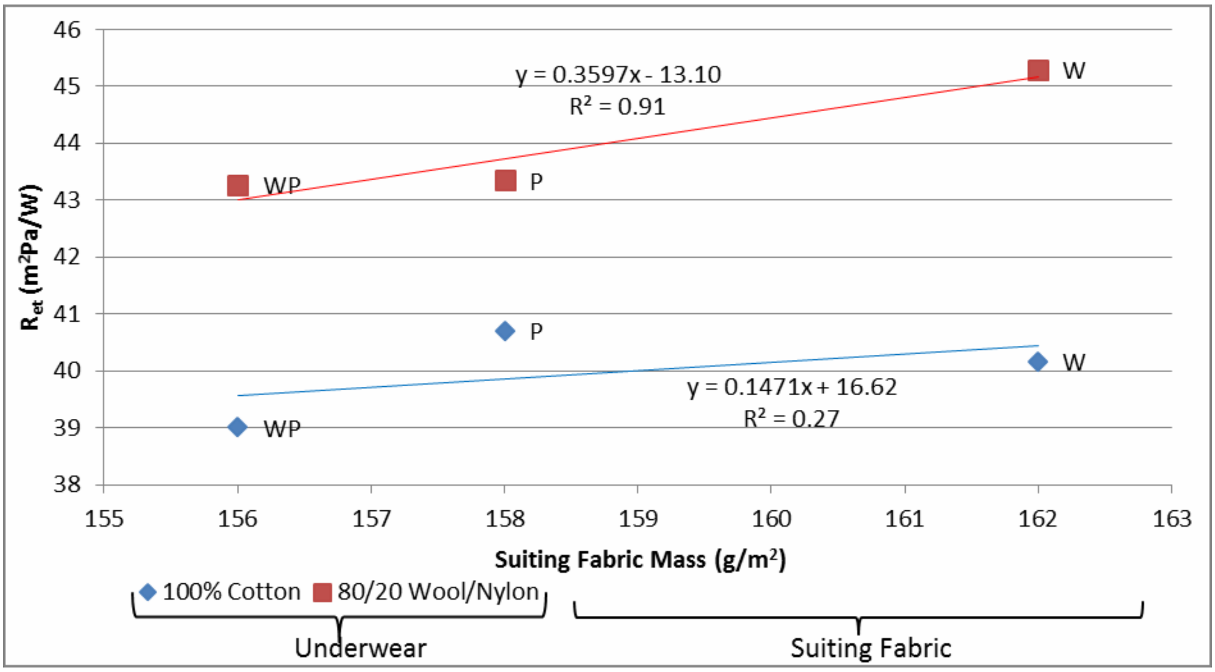

FIGURE 4: CLOTHING ENSEMBLE WATER VAPOUR RESISTANCE (R_{et}) *VS* SUITING FABRIC MASS

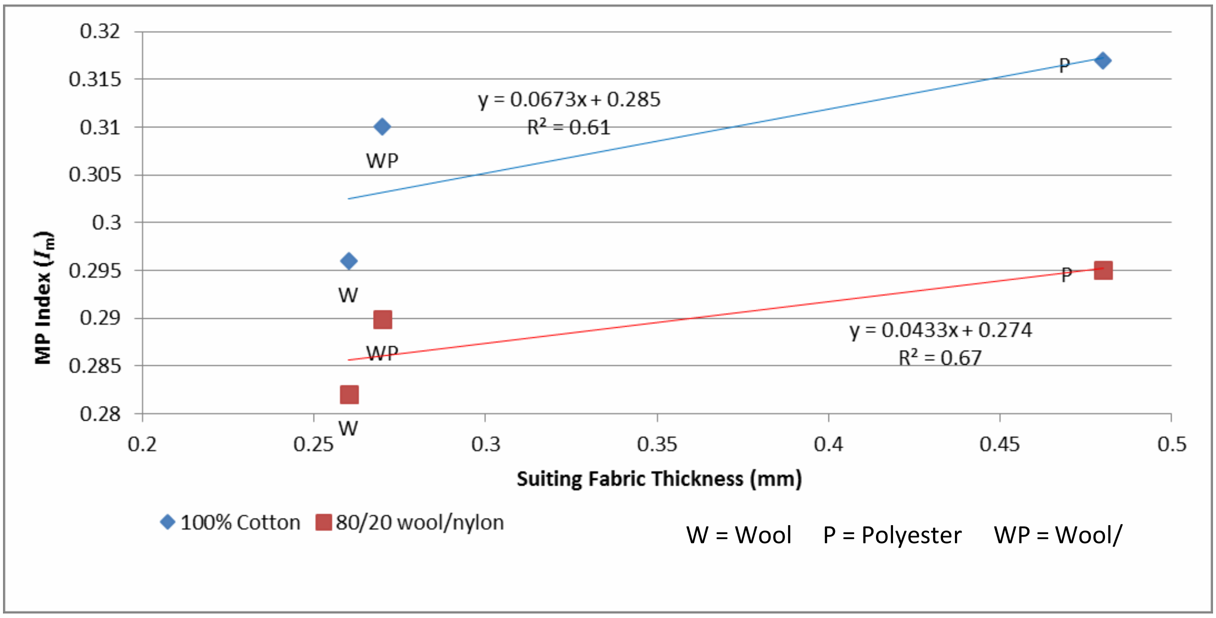

FIGURE 5: CLOTHING ENSEMBLE MOISTURE PERMEABILITY (MP) *VS* SUITING FABRIC THICKNESS

known effects of such associated changes in fabric parameters, on the comfort related properties, are allowed for, as illustrated in Figures 3 to 6, by appropriate graphical plots and regression lines, it appears reasonable to conclude that the observed changes in the comfort related properties of the clothing ensembles can largely be explained by changes in fabric structural parameters, such as thickness, mass and density, rather than by changes in the suiting fabric blend *per se*. Fibre blend level *per se* of the suiting fabric appears to have neither a large nor a consistent effect on the ensemble comfort related properties, once allowance is made for any associated changes in fabric structural related parameters, such as thickness and density. The notably different behaviour of the ensemble containing the 100%

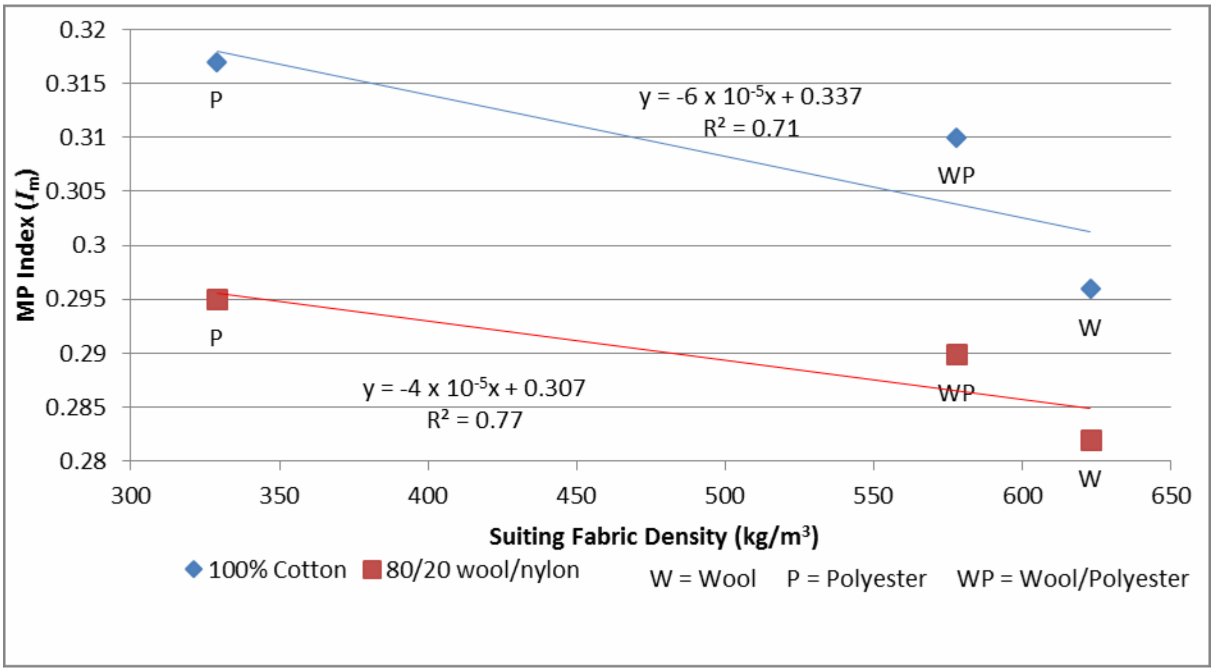

FIGURE 6: CLOTHING ENSEMBLE MOISTURE PERMEABILITY (MP) *VS* SUITING FABRIC DENSITY

polyester fabric suit has been discussed in the previous section.

It is important to emphasize, that this is a preliminary investigation, and a much larger one, incorporating a far wider range of fabrics and fibre blends, is necessary to verify these initial findings, particularly if one takes into consideration the small changes in fabric parameters associated with changes in fibre type as well as the observed significant effect of the type of underwear on the comfort related properties of the clothing ensemble, tentatively ascribed to differences in the underwear fabric thickness and density, rather than fibre type. This, however, needs further investigation and the verification of a more comprehensive study involving a wider range of locally available commercial fabrics. This is currently in progress.

CONCLUSION

Results obtained during this preliminary investigation of the comfort related properties, as measured on a thermal sweating fabric manikin (Walter™) and using clothing ensembles comprising different fibre types that were fairly typical for South Africa, tend to support related studies on fabrics, namely that fabric structural parameters, notably thickness, mass and density, rather than fibre type *per se* (i.e. fibre substance) have the main effect on the measured comfort related properties, such as thermal and water vapour resistance. Nevertheless, the association between fibre blend level and suiting fabric structural parameters complicated isolating the effect of fibre blend level from that of the fabric structural parameters. This was probably also the case for many past studies on fabrics which aimed to compare the comfort related properties of different fibre types and blend levels. A much more detailed investigation, covering a far wider range of fabrics and fibre types and blends is necessary, and is in fact underway, in order to arrive at more meaningful and reliable conclusions concerning the relative importance and effects of fibre substance *vis-a-vis* fabric structural parameters, on fabric and clothing comfort.

This investigation once again highlights the danger of attributing differences in comfort related properties to differences in fibre type *per se* (i.e. fibre substance) or blend level, without taking into consideration, or allowing for, the possible role or effect of differences, however small, in fabric structural parameters, notably thickness, density and porosity, associated with the different fibre types or blend levels. These factors could in fact explain the contradictory findings reported in the literature.

In this context, it is also important to mention, that there is a danger in translating, or directly applying, findings based upon instrument

measured comfort related properties, such as thermal and water vapour resistances, to actual wearer comfort in practice, considering the widely different wearer activities, characteristics and environments. This is important when comparing the comfort of natural hygroscopic or hydrophilic fibres with those of synthetic hydrophobic fibres, particularly in the light of wearer trials often favouring the former, and instruments often the latter, or neither. Within this context, it should also be noted that the important buffering effect (e.g. heat of absorption) of hygroscopic fibres, such as wool, which can add to comfort, is generally not measured or taken into consideration when using instruments to measure and compare the comfort related properties, notably thermal and water vapour resistance, of fabrics and clothing comprising different fibre types.

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