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Effect of Protective Clothing Fabrics Characteristics on the Thermal Comfort Properties

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Abstract: ***This paper focuses on Protective clothing fabrics comfort characteristics that are Flame Resistance, Heat loss, thermal Resistance, Breathability, water vapor resistance, weight and thickness. In this study, Protective clothing consists of two layers: outer layer and cloth lining. Will be evaluated for the effectiveness of thermal comfort properties 7 different fabrics will be used: 100%Nomex, 50% Nomex\50%Wool, 100%wool, 65% polyester\35%viscose, 100% microfiber polyester, 50 %cotton\50%polyester and 100%cotton are tested for thermal Resistance, air permeability, water vapor resistance, weight and thickness. The fabrics which have the best properties were used to cloth lining for protective clothing. For the outer layer: 100%Nomex, 50% Nomex\50%Wool, 100%wool fabrics were tested for thermal comfort such as: flame resistant, thermal Transmittance, heat loss and the fabric that have the best properties was used to make outer layer of protective clothing.***

Keywords: Protective clothing, Comfort properties, Flame Resistance, heat loss, Nomex.

1. Introduction

The thermal comfort properties of fabric and it's ability to maintain the temperature of skin Through transfer of heat and perspiration [1, 2]. Thermal comfort depends on combinations of clothing, climate, and physical activity. thermal comfort is one of the most significant attributes when purchasing textile and apparel products [3.4]

Protective clothing, such as children's sleepwear, work wear for emergency services and military personnel require properties such as heat transfer, thermal protection, good breathability, moisture permeability, absorption of water, flame resistance (FR). [5, 6] Moisture affects heat protection of garments, When moisture within clothing layers is exposed to a sudden heat it might evaporate, move close to the skin and cause burns.[7, 8, 15] this Burns are a significant cause of injury and death.

The addition of layers creates air gaps which can hinder the ability of sweat to evaporate to the outward environment. Also humid conditions can play a role in reducing evaporation. [9.10] Inner wear (cotton underwear), While affordable and allowed under current industry safety standards, can have serious drawbacks, even if it is treated to be flame-resistant.[11, 12] Firstly, the cotton absorbs moisture and holds it close to the skin, which will make it uncomfortable with the possibility of significant steam burns. Also, in some accident situation it may actually ignite, causing more injuries than if there was no base layer at all.[13, 14] underwear garments made of FR fibers will not burn or ignite when exposed to flame. These fabrics are comfortable, have quick drying and moisture wicking properties can be worn in extreme conditions.

A comprehensive FR clothing study for outer and inner wear including various types of fabrics needs to be present to provide maximum comfort, while keeping appropriate protective for all items of clothing worn.[14, 17, 22]

When comparing ignition properties for different fabrics. Natural cellulosic fibers (cotton, linen), manufactured cellulosic fibers (acetate, lyocell, and rayon), burn with a yellow flame, light smoke, and have glowing embers, synthetic fibers (acrylic, nylon, polyester, and spandex) will catch fire quickly and shrink from the flame, sputter, flame, and melt. Wool and silk are protein fibers and are difficult to ignite. They may self-extinguish, depending on finish treatments and the closeness of the weave, knit. [16, 17, 18, 25]

2. Experimental work

2.1. Tested fabrics specifications

In this study, used Protective Clothing Fabrics formed two layers. Shown in Figure 1, Fabrics used for outer layer are (100%Nomex - %Nomex\ %Wool-100%wool), Fabrics are used for cloth lining are (65%polyester\35%viscose- 100% microfiber polyester- 50% cotton\50%polyester-100% cotton). Specifications of the tested fabrics have shown in table 1.

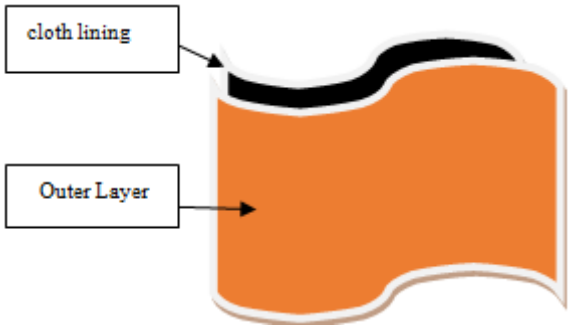

Figure 1: Fabrics are used for outer and cloth lining layers

Table (1) Specifications of the tested fabrics.

No.	fabrics	application	Weave pattern	Weight g\m^2	Thickness m.m	Water vapor resistance (R_{et}) Pa.m^2.w^{-1}	Air permeability Cm^3\cm^2\sec.	thermal Transmittance (R_{ct}) mk.m^2.w^{-1}
1	100%Nomex	Outer layer	1\1 plain	1.80	0.03	4.96	10.06	4.4
2	Nomex\Wool 50:50	Outer layer	1\1 plain	1.25	0.02	3.7	19.69	9.1
3	100%wool	Outer layer	1\1 plain	2.45	0.13	5.6	23.34	9.9
4	polyester\viscose 65:35	cloth lining	1\1 plain	1.22	0.02	1.97	21.6	3.8
5	100% microfiber polyester	cloth lining	1\1 plain	1.21	0.02	1.90	3.12	8.5
6	cotton\polyester 50:50	cloth lining	1\1 plain	1.14	0.02	2.03	74.96	6.2
7	100% cotton	cloth lining	1\1 plain	1.22	0.04	1.61	90.37	2.5

2.2. Experimental tests. [27, 28.29]

All tests were carried out in National Institute for Standards after the samples were conditioned under standard atmospheric conditions(temperature 20 ± 2°C, 65 ± 2% relative humidity), according to standard ISO 139:1973.

Measuring properties are weight, thickness, water vapor permeability, air permeability, Thermal Transmittance and heat loss For all seven fabrics. But there are three fabrics which used outer layer in Protective Clothing, measuring fire resistance FR. the properties of each single fabric 1, 2, 3, 4, 5, 6, 7.was measured separately and then one layer composite of the two fabrics were the best properties can use in Protective Clothing.

1) **Weight** of fabric measurements were carried out according to ASTM Standards.D1910-64(1970).
2) **Thickness** of fabric measurements were carried out according to AATCC Test Method 147-2011.
3) **Water vapor permeability** measurements were carried out according to ISO 11092:2014.
4) **Air permeability** measurements were carried out according to ASTM - D 737.
5) **Thermal Transmittance** of textile materials measurements were carried out according to ISO 11092:2014.
6) **Heat loss** measurements were carried out according to ISO 11092:1993
7) **Fire resistance FR** (Limiting Oxygen Index LOI Tester), measurement of Oxygen index(OL), burning rates(BR) and char length (CL) according to ASTM D2863-97, Measuring the percentage of oxygen necessary to incinerate the material the idea of the test is to subject the material to a mixture of oxygen and nitrogen and calculate the time of incineration and the amount of oxygen used for it, there is an inverse relation between the amount of burnet oxygen and the material resistance to incineration.

3. Results and Discussion

3.1. Properties of underwear fabrics.

Results of experimental examination on the produced samples are presented in the following tables and graphs Results were statically analyzed for data listed, table 1&2.

Table 2.Fire resistance FR for outer and middle layer fabrics in protective Clothing

No	fabrics	Fire resistance FR			Heat loss seconds
		Oxygen index (OI)%	Char length (Ch) mm	Average burn time. mm/s	
1	100%Nomex	3	112	81	2408
2	Nomex\Wool 50:50	6	pass	7	3032
3	100%wool	6	pass	5	3490

Where : pass= did not ignite.

3.1.1. Weight

Weight is predictive of comfort, fabrics that are rated as most comfortable are1 to 2.5 g\m2 heavier than the lightest fabrics in the tests [15].

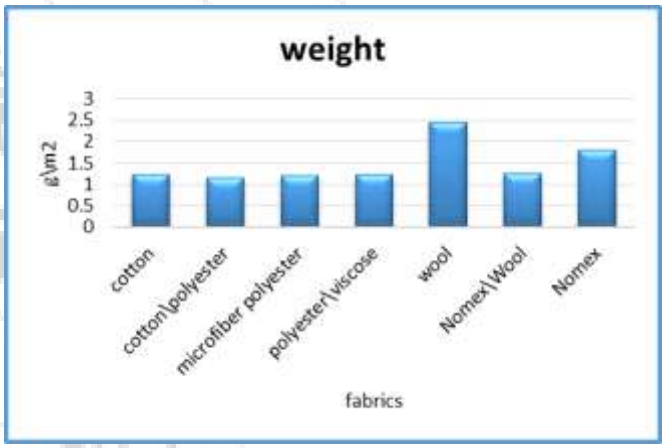

Figure 2: Weight behavior of the fabrics.

The values are given in Table 1& Figure 2 show the Weight behavior of the fabrics.

These results follow the order: 100%wool>100% Nomex> Nomex\wool >cotton= viscose\polyester= 100% microfiber polyester> cotton\polyester.

It can be noticed that 100% wool has the highest weight when compare with another fabric, but cotton\polyester has the lowest result.

It can be noticed that, cotton, viscose\polyester and 100% microfiber polyester fabrics are given the same results.

3.1.2 Thickness

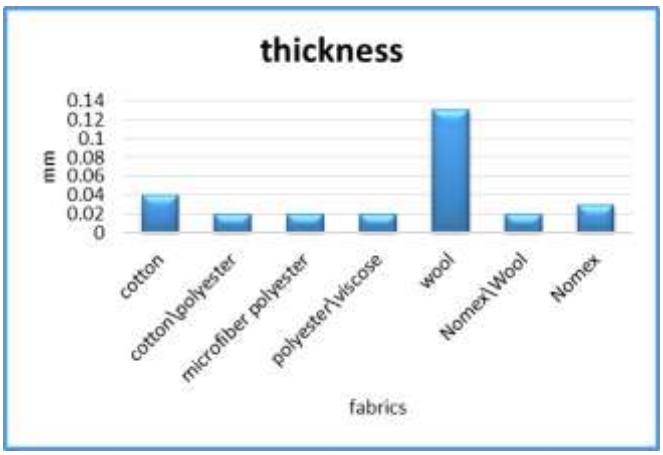

Figure 3: Thickness of the fabrics.

Thickness appears to be the major determinant of insulation. For normal, permeable materials, clothing material thickness also determines the major part of the thermal comfort. The values are given in Table 1& Figure 3 show the thickness behavior of the fabrics. It can be noticed that, 100% wool has the highest thickness (0.13mm) when compared with other fabrics. The thickness values of the other tested fabrics are close.

3.1.3. Water vapor resistance.

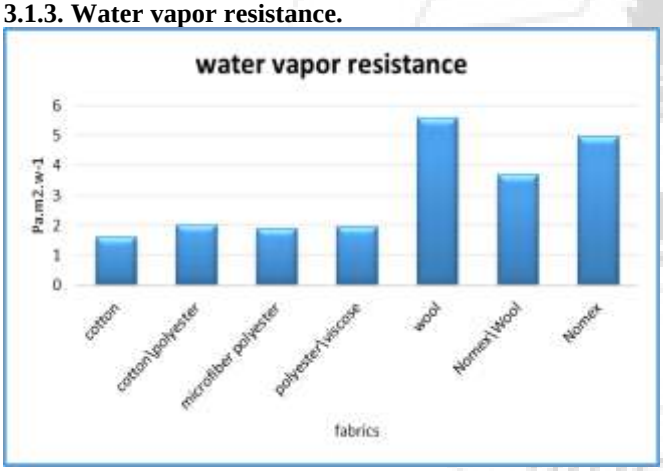

Figure 4: Water vapor resistance (Ret)

Water vapor resistance (Ret) is one of the most important properties that determine the velocity of water vapor transmission through a textile material. This is a vital Parameter in appraising comfort characteristics of a fabric, as it stands for the Capability of transporting perspiration. the values are given in Table 1 and Figure 4.

Water vapor resistance values of Nomex fabric was higher than other fabrics, and100% cotton fabric was lower than all other fabrics. The polyaramide obtained known under the trade name Nomex is low absorption water 3% only. Comparing all the fabrics, in samples with cotton.

cloth lining generally more moisture was accumulated in the underwear than in the respective samples with cotton. However, the amount of moisture stored in the underwear strongly depended on the type of the neighboring station uniform layer. [18, 19, 20]

3.1.3. Air permeability

Air permeability is defined as, the amount of ambient air that flows under the garment after passing through the fabric. For protective clothing, garment design improvements comfort properties first layer of clothing, may be added to increase the air flow from skin throw fabrics layers(breathability) in protective clothing.[15, 19, 20]

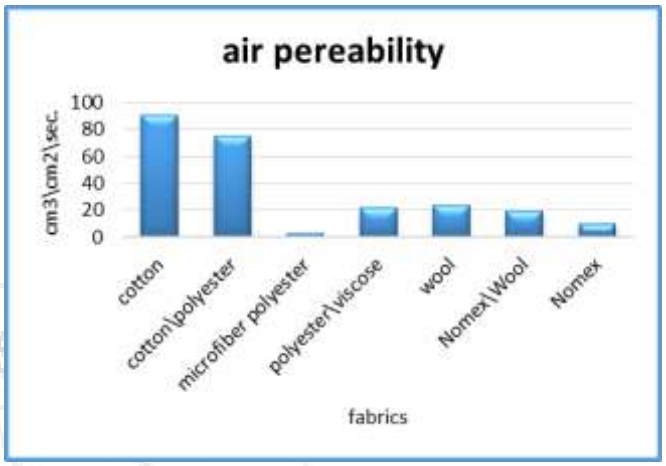

Figure 5: Air permeability

The values are given in Table 1& Figure 5 show the air permeability behavior of the fabrics These results follows the order:100%cotton>cotton\polyester>wool> iscose\polyester> Nomex\wool> Nomex > 100% microfiber polyester It can be noticed that 100% microfiber polyester has the lowest air permeability when compared with another fabric, but 100%cotton has the highest result. It can be noticed that, this result may be attributed to higher air permeability of 100% cotton fabric, it can be used in cloth lining.

3.1.4. Thermal Transmittance (Rct)

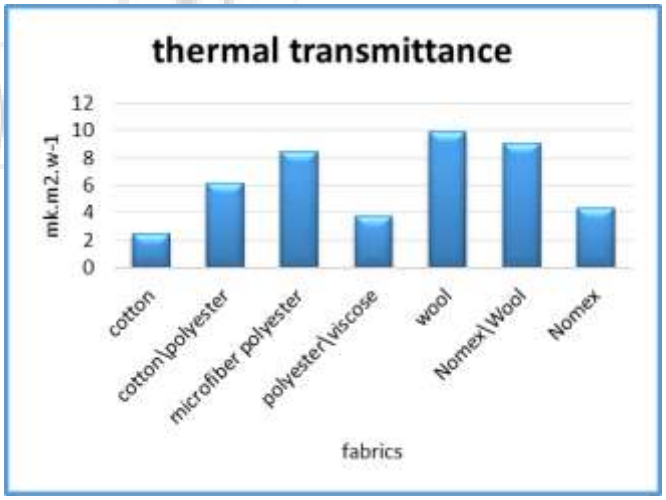

Figure 6: Thermal Transmittance (Rct)

The values of the thermal resistance (Rct) of the tested fabrics are listed in Table 1&figure 6. The Rct values of 100% wool and Nomex fabrics were higher than the values of all other fabrics. so wool and Nomex can provide better thermal insulation and warmer feeling at the initial touch with

lower thermal absorptivity value. It can be used for outer layer in protective clothes. This behavior is in a great extent influenced by the fabric with the lowest thickness and weight [9, 10]

From this part we can conclude, cotton fabric is used for cloth lining. Because this fabric has good comfort properties: weight, thickness, water vapor permeability, air permeability, Thermal Transmittance and heat loss. Show figure 7.

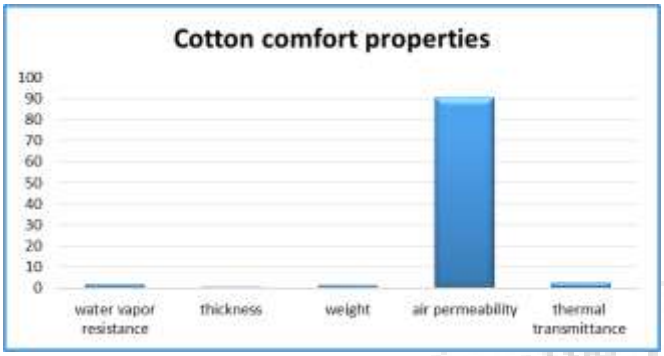

Figure 7: Comfort properties of cotton fabric.

3.2. Thermal comfort fabrics are used for outer layer in protective cloth.

3.2.1.-Evaluation of Fire resistance fabrics

100% wool	Wool\Nomex 50/50	100% Nomex

Figure 8: The digital photos for the tested sample after vertical burning tests.

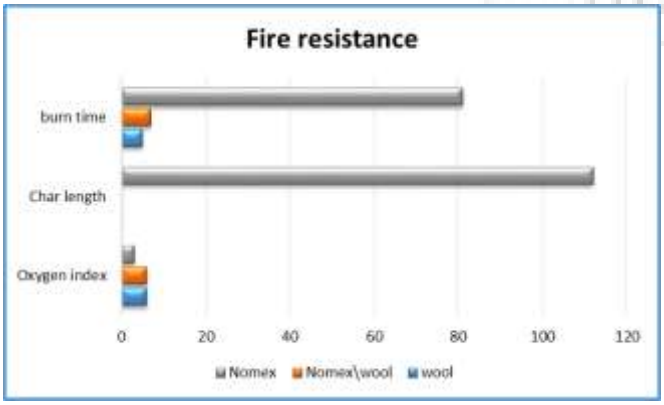

Figure 9: Evaluation of Fire resistance of fabrics

Fire resistance is measuring of Oxygen index (OL), burning rates (BR) and char length (CL).

3.2.1.1. Average burn time, second

The data of Average burn time for tested fabrics as shown in figure8& 9 and table 2 indicates little decrease in average burn time for 100% wool it take 5 second burn time, the next wool\Nomex fabric take 7 second burn time, the last 100% Nomex take 81 seconds burn time. This can be attributed, wool and wool\Nomex fabrics have best burn time result.

3.2.1.2. Oxygen index (OI).

The data of Oxygen index (OI) for tested fabrics as shown in figure 8& 9 and table 2 indicates little decrease in Oxygen index (OI) for 100% Nomex, it take 3%, the next wool\Nomex and 100%wool fabrics take 6%. This can be attributed; wool\Nomex and 100%wool fabrics are the best result for Oxygen index (OI).

3.2.1.3. Char length (CL).

The data of Char length (CL) for tested fabrics as shown in figure 8& 9 and table 2 indicates the increase Char length (CL) for 100% Nomex, it take 112 mm to burn, but wool\Nomex and 100%wool fabrics recorded result low length to burn. This can be attributed to wool\Nomex and 100%wool fabrics are the best result Char length (CL).

The results of Fire resistance(Oxygen index, burning rates and char length) indicate that Nomex fabric is Synthetic material, it has a long chain amide linkages (-NH-CO-), having at least 85% of it s attached directly to two aromatic rings. Aramid fibers exhibit low flammability, high temperatures and high modulus.

Wool has a complex composition that is based on a unique cell structure, high nitrogen and water content makes it naturally flame resistant, Wool does not ignite easily and will often self-extinguish and burn it does not melt while burning.[14, 17, 22]

3.2.2. Heat loss

combinations fabrics	Thickness m.m	Weight g\m^2	Water vapor resistance Pa.m^2.w^{-1}	Air permeability Cm^3\cm^2\sec.	thermal Transmittance mk.m^2.w^{-1}
Wool outer layer-cotton lining cloth.	0.17	3.67	7.21	113.71	12.4

The values of heat loss of the tested fabrics are listed in Table 2&figure 10. The heat loss values of 100%wool and Nomex\wool fabrics were higher than the values of Nomex fabric. so wool and Nomex\wool can keep heat of skin and can provide warm feeling. This fabrics can be used for outer layer in protective clothes.

Heat can transfer from skin by breathability, radiation and sweating. Therefore the insulation is dependent on the thickness of the material (that is the enclosed air layer) breathability is a viable approach for increasing heat loss.[23, 26]

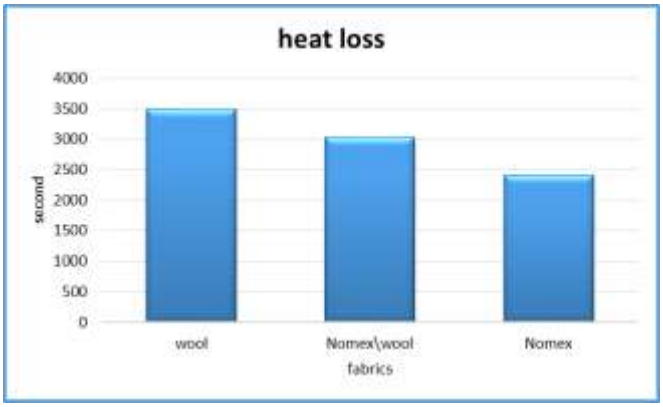

Figure10. Heat loss of fabrics

From this part we can conclude, wool fabric used for outer layer in protective cloth. Because of this fabrics good thermal properties: fire resistance (Oxygen index, burning rates and char length), Thermal Transmittance and heat loss. Shown figure 11

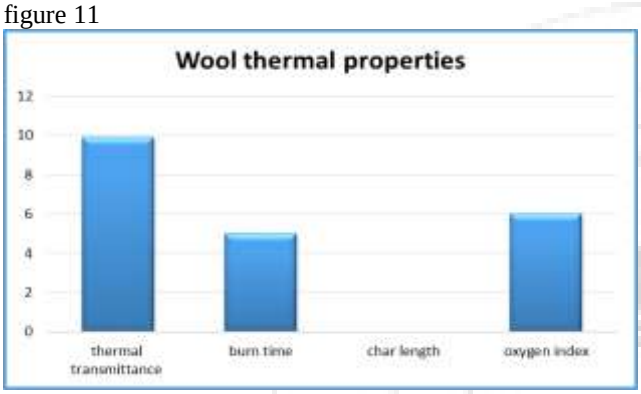

Figure 11.thermal properties of wool fabric

3.3. Properties of layer combinations with fabrics in protective clothes.

Protective clothes such as children's sleepwear and work wear consist of two layers. Thermal comfort properties composite layers between outer layer and cloth lining become important. The results of comfort properties for tested fabrics indicate that, wool fabric is the best thermal comfort can use to outer layer and cotton fabric is the best comfort properties can use to cloth lining. Show table 3& figure 12.

Table 3: Properties of layer composite fabrics in protective clothes.

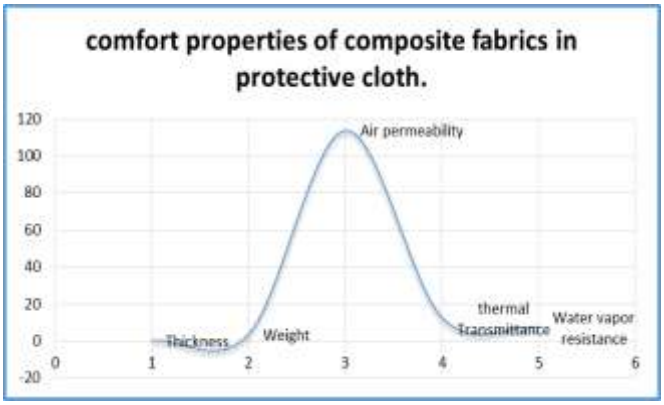

Figure 12: Comfort properties of composite fabrics in protective cloth.

4. Conclusion

In this study, Protective clothing consists of two layers: outer layer and cloth lining.

To evaluate the effectiveness of thermal comfort properties of the two layers, 7 Fabrics were used: 100% Nomex, 50% Nomex \50% Wool, 100%wool, 65% polyester \35% viscose, 100% microfiber polyester, 50%cotton\50% polyester and 100% cotton tested For thermal Resistance, air permeability, water vapor resistant, weight and thickness.

the fabric which have the best properties was used to cloth lining for protective clothing.

But 100%Nomex, 50% Nomex\50%Wool, 100%wool fabrics were tested for thermal comfort such as: flame resistant, thermal Transmittance, heat loss and the fabric that have the best properties was used to make outer layer of protective clothing.

The results indicate that cotton fabric has higher air permeability, water vapor permeability, weight, thickness and thermal Resistance. So cotton fabric provides better comfort properties, According to these results, cotton fabric can be used in cloth lining.

The results indicate that wool fabric has higher flame resistance, thermal Transmittance, heat loss and the fabrics that have the best properties was used to make outer layer of protective clothing.

So wool fabric provides better thermal insulation and warmer feeling at the initial touch with lower thermal absorptive value.

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