THE EFFECTS OF LAUNDERING WITH AND WITHOUT FABRICS SOFTENERS AND DRY CLEANING ON THE THERMAL PROPERTIES OF BLANKETS

by

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INTRODUCTION

The purpose of this study was to investigate the effects of fabric softeners, repeated launderings and dry cleanings on the thermal insulative properties of blankets. Other properties that were evaluated included thickness, air permeability, and dimensional changes due to cleaning procedures.

The first part of the thesis, Paper for Publication describes the significance of the study, the methods and materials used for testing, and an overview of the test results. The second part of the thesis, Appendix, describes in detail the procedures used in operating the quarded hot/cold plate and presents a more complete tabulation of research data. A more extensive review of literature and list of references also is presented in the second section.

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ABSTRACT

Evaluated in this study were the effects of repeated launderings, with and without fabric softeners, and dry cleanings on the thickness, air permeability, dimensional stability, thermal conductivity, and clo values of two blanket fabrics. The softeners used included one which was added to the rinse in laundering and one which was added to the dryer. The changes in the thermal transmittance properties of the test fabrics were determined with a guarded hot/cold plate.

Results showed that blanket thickness was significantly decreased after repeated launderings and dry cleanings. Significant changes in dimensional stability occurred during the first few washings. There also was a significant change in air permeability of the blanket fabrics after laundering and dry cleaning, with the air permeability increasing for one blanket fabric and decreasing for the other. There was no significant change, however, in the thermal conductivity of the blankets after repeated launderings, with or without fabric softeners, or after repeated dry cleanings. Thus, the thermal insulative properties of blankets were not affected by repeated cleanings or by the use of fabric softeners during laundering or drying.

INTRODUCTION

As an essential article in every home, blankets are used primarily for warmth. When the body is sleeping, less energy and heat are produced, thus requiring covering to maintain normal body temperature. In addition, the widespread concern over saving energy has caused many consumers to lower thermostats or even to turn the heat completely off at night, resulting in the need for either more or warmer blankets. The ultimate goal of blanket manufacturers is to produce a blanket that affords warmth without weight. New blankets are generally soft, fluffy, and characteristically "warm". Through subsequent laundering or dry cleaning, however, these properties are frequently decreased, which may result in reduction of the thermal insulative qualities of the fabric.

Fabric softeners are frequently added to the household wash to maintain the soft, fluffy hand of fabrics. The most common type of fabric softeners sold for domestic use are quaternary ammonium salts (cationic compounds), having long hydrocarbon chains which reduce friction and increase the tactile sensation of hand. Cationic softeners also are effective as anti-static agents, especially on hydrophobic, man-made fibers. The nitrogen containing end of the softener molecule has an affinity for moisture, thereby dissipating the electrical charges on the fabric surface that may have resulted from rubbing of the fabric against itself or another surface (11). It has been postulated that increased moisture absorbency may decrease thermal insulation, since water is a good conductor of heat.

Many studies indicate that thermal insulation is most dependent on the thickness of the material; thus, the thicker the fabric, the greater the insulation (3,4,5,7,8,9). Because air is a poor conductor of heat, insulation is increased as porosity increases, as long as the air remains still within the fabric structure. Consequently, the purpose of a raised or napped surface on a blanket or a cellular structure within a blanket is to entrap air for insulation (10).

Proper cleaning methods should be selected to maintain the thermal insulative properties of textiles used primarily for warmth, however, little research is available in this area. In a study done by Schiefer et al. (8) it was found that laundering had little effect on the thermal transmission characteristics of household blankets. Shrinkage due to laundering caused an increase in thickness while decreasing compressibility. These two factors often affect the thermal transmission characteristics of textiles such as blankets. Decreased compressibility is a result of the fibers becoming matted together, thus increasing the conductance from fiber to fiber. Consequently, the two changes tended to compensate each other, yeilding no apparent change in conductivity. There also was little difference between the effects of laundering and dry cleaning on the thermal transmission properties of the test blankets.

This study evaluated the effects of repeated launderings, with and without fabric softeners, and repeated dry cleanings on the thermal properties of blanket fabrics. Two widely used commercial softeners were chosen for this study. One was representative of the type which is added to the rinse cycle and the other was representative of the type which is added to the dryer. Blankets were evaluated before and after two and five launderings and two and five dry cleanings.

EXPERIMENTAL

Materials

Two blanket fabrics were selected for this study. Blanket I was a 100% acrylic (329.6 g/m^2, 9.7 oz./yd.^{2}) napped plain weave fabric having a fabric count of 13.9 X 10.9 threads per centimeter. Blanket II was constructed of two layers of 100% nylon fibers bonded to polyeurethane foam, sandwiched together by a scrim. Blanket II weighed 215.5 g/m^2 (6.4 oz./yd.^{2}).

From each test fabric, three specimens measuring 60.9 X 60.9 cm (24 X 24 in.), were cut for each cleaning procedure, giving a total of twelve specimens per fabric. Within each blanket type, the specimens were randomly cut from a 5.5 meter (6 yd.) length of test fabric and assigned to the four various treatment groups designated below. No sample was taken closer to the selvage than one tenth the width of the fabric.

Group A - washed with detergent alone, tumble dried

Group B - washed with detergent and fabric softener added to the final rinse, tumble dried

Group C - washed with detergent and fabric softener added to the tumble dryer

Group D - dry cleaned at a commercial cleaners

A 25.4 X 25.4 cm (10 X 10 in.) reference square was marked on the face of each test specimen. Two replications were carried out to ensure repeatability of experimental results. All test specimens were conditioned prior to testing. The blankets were chosen on the basis that they were two of the most common blankets available to the consumer.

Laundering

Groups A, B, and C, previously described, were laundered using a Sears Kenmore washer, Model No. 600 and a Sears Kenmore automatic clothes dryer, Model No. 62611, Series 72611. The blankets were laundered and tumble dried at a temperature of $40.6 \pm 2.8^{\circ}$ C ($105 \pm 5^{\circ}$ F), indicated as "WARM" on the machines. Specimens were washed for 15 minutes, rinsed for 15 minutes, and then tumble dried for 30 minutes. A standard wash load was maintained at 1.8 kg (4 lbs.) by adding ballast to the wash. The procedure in AATCC Test Method 124, Appearance of Durable Press Fabrics after Repeated Home Launderings (1), was followed for laundering, using AATCC Standard Detergent 124. The blankets were evaluated for thickness, air permeability, dimensional stability, and thermal transmittance before and after two and five washings and dryings.

Dry Cleaning

Specimens in Group D were commercially cleaned in an 18.2 kg (40 lb.) single bath dry cleaning machine, Model No. VIC 221-1, Vick Mfg. Co. Relative humidity was approximately 30-40% at $40.6 \pm 2.8^{\circ}$ C ($105 \pm 5^{\circ}$ F), and solvent temperature was 18° C (90° F). A 4 minute cleaning cycle was followed by a 36 minute drying cycle. The perchloroethylene solvent used in dry cleaning was charged with a 1.3% anionic detergent (Staticol). A standard load of 1.8 kg (4 lbs.), again, was maintained by adding ballast. The dependent test variables were evaluated on the blankets before and after two and five dry cleanings.

Thickness

The procedure in ASTM Test Method D 1518-64, Thermal Transmittance of Textile Fabric and Batting Between Guarded Hot-Plate and Cool Atmosphere

(2), was followed for determining the thickness of the test specimens before and after subsequent laundering and dry cleaning. Specimens were measured using the Frazier Compressometer under 0.07 k N/m^2 (0.01 psi). A 7.62 cm (3 in.) presser foot was used. An average of five readings was recorded for the thickness of each specimen.

Dimensional Change

The procedure in ASTM Test Method D 2724-72, Bonded and Laminated Apparel Fabric (2), was followed for evaluating the dimensional changes which occurred in the blankets after laundering and dry cleaning. During specimen preparation, three sets of reference markings were applied 25.4 cm (10 in.) apart to form a reference square centrally located on the face of each test specimen. After each laundering or dry cleaning, the percentage dimensional change was determined for both the warp and filling directions of the test fabrics, using Equation 1.

$$\%\ \text{Dimensional Change} = \frac{\text{width before cleaning} - \text{width after cleaning}}{\text{width before cleaning}} \times 100 \quad (1)$$

Air Permeability

The procedure in ASTM D 737-75, Air Permeability of Textile Fabrics (2), was followed for evaluating the air permeability of the blanket fabrics before and after laundering and dry cleaning. The Frazier Air Permeability Testing Machine that was used for the test, is composed of two manometers which are filled with Turkey red oil (one is a horizontal manometer that measures pressure and the other is a vertical manometer that measures air flow). Depending on the porosity of the fabric, the appropriate nozzle was selected so that the vertical manometer would register between 3 and 13 inches (Note: Instrument scales were in inches not in SI units). The greater the air permeability of the fabric, the larger the nozzle that was required. Air permeability is measured by the volume of air flowing in unit time through a unit area of the material when the pressure differential between the two fabric surfaces is 124 pascals (0.5 in. of water). Using the calibrated chart which accompanied the testing apparatus, readings from the vertical manometer were converted from inches to $(ft^3/min)/ft^2$ of fabric, and then to $(m^3/s)/m^2$ of fabric. The mean air flow for each specimen was based on the conversion of five readings.

Thermal Transmittance

The procedure in ASTM Test Method D 1518-64, Thermal Transmittance of Textile Fabric and Batting Between Guarded Hot-Plate and Cool Atmosphere (2), was followed for measuring the thermal transmission characteristics of the test specimens.

The apparatus used was a guarded hot/cold plate which was constructed at Kansas State University for the Department of Clothing, Textiles, and Interior Design and co-housed in the Institute for Enviromental Research. The guarded hot/cold plate is composed of a test plate and guard ring which are maintained at a constant temperature during testing (2). Thermal transmittance was measured by the rate of heat loss through the fabric into the air by recording the amount of energy required to maintain the test plate at a constant temperature. In order to determine the amount of power loss, it was necessary to calibrate the instrument using a material having a known thermal conductivity coefficient. For this study, a fiberglass insulation board from the National Bureau of Standards was used to calibrate the instrument. After allowing the specimens to reach equilibrium with the conditions in the test chamber, readings from the specimens were taken every 3 minutes over a period of 30 minutes.

The guarded hot/cold plate was operated in a 2.44 X 3.05 m (8 X 10 ft)Shere enviromentally controlled test chamber. The test conditions in the test chamber were: 20 ± 1.4° C (68 ± 2.5° F), 50% r.h., and air velocity of approximately 10 cm/sec (20 ft/min). The temperature of the test plate and guard ring was maintained at 35.6 ± 0.28° C (96 ± 0.5° F).

The intrinsic thermal transmittance coefficient of the fabric alone, U_2, was calculated using Equation 2 (2), which is based upon the values derived from the combined thermal transmittance coefficient of the specimen plus air, U_1, and the bare plate thermal tramsittance coefficient, U_{bp}. U_1, U_2, and U_{bp} were expressed in $Btu/h \cdot ft^2 \cdot {}^{o}F$ and converted to $Watts/(meter \cdot {}^{o}K)$. Equation 3 (2) was used to calculate U_1. U_2 was similarly calculated, using the bare plate values.

$$U_2 = (U_{bp} \times U_1)/(U_{bp} - U_1) \tag{2}$$

$$U_1 = P/(A \times (T_p - T_a)) \tag{3}$$

where: P = power loss from test plate in Btu/h.*

A = area of test plate, ft^2.

T_p = test plate temperature, °F.

T_a = air temperature, °F.

After the thermal transmittance coefficient was calculated, the following values also were determined: Specific conductivity coefficient for a unit thickness of test specimen (k), using Equation 4 (2); and

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*For calculation of P, see Master's Thesis, The Effects of Laundering With and Without Fabric Softeners and Dry Cleaning on the Thermal Properties of Blankets, by Marjorie Wann Baker, Kansas State University, Manhattan, Kansas, 1978.

intrinsic Clo, a thermal resistance unit developed by Gagge, Burton, and Bazette (5), using Equation 5 (2).

$$k = U_2 \text{ X thickness} \tag{4}$$

$$\text{Intrinsic Clo} = 1.137/U_2 \tag{5}$$

Statistical Analysis

An analysis of variance procedure of split-split-plot experiment was performed on the data obtained from thickness, dimensional stability in both warp and filling directions, air permeability, and thermal conductivity (k), before and after subsequent laundering and dry cleaning. The least significant difference (L.S.D.) test was used to analyze the main effects and interactions only if F was significant in the analysis of variance tests. The level of confidence established was 0.05.

RESULTS AND DISCUSSION

The thickness, air permeability, dimensional change, specific conductivity coefficients and intrinsic Clo values of the test specimens were determined before and after two and five launderings, with and without fabric softeners, and before and after two and five dry cleanings. The data collected from the physical tests on Blanket I and Blanket II are presented in Tables 1 and 2, respectively.

Fabric Thickness

The effects of repeated launderings with and without fabric softeners, and dry cleanings on the thickness of two types of blankets are shown in Figure 1. An analysis of variance (ANOVA) statistical test was performed on the mean thickness values obtained for the blankets before and after two and five launderings and dry cleanings. The independent variables (main effects) in the analysis were type of fabric or material (Blanket I or Blanket II), number of cleanings (0, 2, or 5), and cleaning procedure (laundering with or without fabric softeners or dry cleaning: Groups A, B, C, or D).

All three main independent variables had significant effects on fabric thickness. Blanket I (100% acrylic) was significantly thicker than Blanket II (100% nylon). After cleaning, the specimens from Group A (washed with detergent alone) and Group D (dry cleaned) had higher mean thickness values than those laundered with the two fabric softeners. Thus, the use of softeners in laundering substantially reduced the thickness of the blankets with repeated laundering. The two softeners had

Table 1: Results of Physical Tests Performed on Blanket I (100% acrylic, napped, plain weave)

Number of cleanings	Cleaning Procedures*	Thickness[a] mm	Air Permeability[b] $(m^3/s)/m^2$ of fabric at 124 pascals pressure	Percentage Dimensional Change[c]		Specific Conductivity Coefficient (k)[d] W/(m·K)	Intrinsic Clo
				Warp	Filling		
0	A	4.66	1.17	--	--	0.0303	1.04
0	B	4.68	1.12	--	--	0.0281	1.11
0	C	4.61	1.31	--	--	0.0267	1.14
0	D	4.71	1.10	--	--	0.0281	1.10
2	A	4.57	1.08	-2.8	-1.9	0.0238	1.23
2	B	4.30	1.06	-2.6	-1.5	0.0252	1.11
2	C	4.37	1.05	-2.8	-1.9	0.0259	1.07
2	D	4.71	1.06	-1.3	-0.2	0.0260	1.18
5	A	4.40	1.03	-3.9	-2.3	0.0231	1.20
5	B	3.95	1.04	-4.2	-2.5	0.0267	1.01
5	C	4.18	1.04	-4.2	-2.5	0.0267	1.01
5	D	4.54	1.04	-1.5	-0.1	0.0267	1.13

*Cleaning Procedures: Group A - washed with detergent alone; Group B - washed, softener added to final rinse; Group C - washed, softener added to dryer; Group D - dry cleaned.

[a] To obtain measurement in inches, divide by 25.4.

[b] To obtain measurement in $(ft^3/min)/ft^2$ of fabric at 0.5 inches pressure, divide by 0.005080.

[c] A negative number indicates shrinkage, whereas a positive value indicates stretch.

[d] To obtain measurement in $Btu \cdot in/(h \cdot ft^2 \cdot {}^\circ F)$, divide by 0.1441.

Table 2: Results of Physical Tests Performed on Blanket II (100% nylon fiber bonded to polyeurethane foam)

Number of cleanings	Cleaning Procedure*	Thickness[a] mm	Air Permeability[b] $(m^3/s)/m^2$ of fabric at 124 pascals pressure	Percentage Dimensional Change[c]		Specific Conductivity Coefficient(k)[d] W/(m·K)	Intrinsic Clo
				Warp	Filling		
0	A	4.13	0.35	--	--	0.0411	0.65
0	B	4.04	0.26	--	--	0.0411	0.65
0	C	3.95	0.37	--	--	0.0468	0.65
0	D	4.04	0.34	--	--	0.0411	0.64
2	A	3.79	0.38	-2.8	2.1	0.0439	0.56
2	B	3.64	0.29	-3.1	1.9	0.0389	0.58
2	C	3.62	0.41	-3.4	2.1	0.0382	0.64
2	D	4.04	0.39	-1.7	1.4	0.0382	0.72
5	A	3.89	0.40	-3.3	2.1	0.0469	0.53
5	B	3.59	0.31	-3.5	2.1	0.0370	0.65
5	C	3.71	0.43	-3.9	2.1	0.0418	0.59
5	D	3.95	0.39	-2.0	1.5	0.0382	0.70

*Cleaning Procedures: Group A - washed with detergent alone; Group B - washed, softener added to final rinse; Group C - washed, softener added to dryer; Group D - dry cleaned.

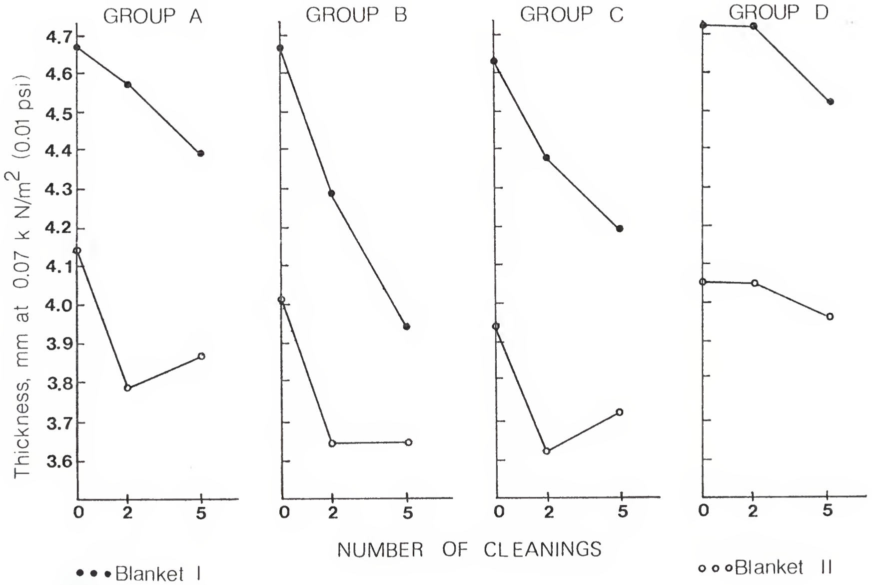
[a] To obtain measurement in inches, divide by 25.4.

[b] To obtain measurement in $(ft^3/min)/ft^2$ of fabric at 0.5 inches pressure, divide by 0.005080.

[c] A negative number indicates shrinkage, whereas a positive value indicates stretch.

[d] To obtain measurement in $Btu \cdot in/(h \cdot ft^2 \cdot {}^{\circ}F)$, divide by 0.1441.

Fig. 1. The Effect of Cleaning on Thickness (Note: Group A - washed with detergent alone; Group B - washed, softener added to rinse; Group C - washed, softener added to dryer; Group D - dry cleaned)


GROUP A
GROUP B
GROUP C
GROUP D
Thickness, mm at 0.07 k N/m² (0.01 psi)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
0
2
5
NUMBER OF CLEANINGS
••• Blanket I
ooo Blanket II

similar effects in reducing thickness with repeated launderings since there was no significant difference between the mean thickness values for specimens in Groups B and C. A progressive decrease in thickness was observed for the specimens as the number of cleanings increased. However, the following second order interactions also had significant effects on thickness: material X number of cleanings and number of cleanings X cleaning procedure.

Blanket I (100% acrylic) had significantly higher mean thickness values than Blanket II (100% nylon) before and after two and five launderings and dry cleanings. Substantial decreases in the thickness of Blanket I occurred as the number of launderings and dry cleanings increased. With Blanket II, however, no additional change in thickness occurred between two and five launderings.

For the specimens from Groups A, B, and C (i.e. the laundered specimens with and without fabric softeners), there was a significant decrease in thickness after two and five launderings when compared with the thickness means for the unlaundered specimens. For Group D (i.e. dry cleaned specimens), a significant decrease in thickness did not occur until after five dry cleanings. In addition, the thickness means for the specimens laundered with the fabric softeners, Groups B and C, were substantially lower than those observed for the dry cleaned specimens in Group D, and the specimens that were washed with detergent alone in Group A. The specimens that were laundered with the softener added to the wash, Group B, had lower thickness values than the laundered specimens in which the softener was added to the dryer, Group C. Thus, dry cleaning had the least effect, while the fabric softener added to the rinse cycle had the greatest effect on reducing thickness.

As shown in Figure 1, Blanket I (100% acrylic) had a decrease in thickness within each cleaning procedure as the number of launderings and dry cleanings increased. In all cases, significant changes in thickness occurred as the number of cleanings increased, except between zero and two launderings with detergent alone (i.e. Group A) and between zero and two dry cleanings (i.e. Group D).

Blanket II, the 100% nylon fiber bonded to polyeurethane foam, showed an overall decrease in thickness after two launderings for Groups A, B, and C, however, there was no change in thickness after two dry cleanings (Group D). Any amount of change which occurred in the thickness of the specimens between two and five launderings and dry cleanings was non-significant.

The percentage change in fabric thickness for Blankets I and II after five cleanings for each cleaning procedure (i.e. Groups A, B, C, and D) are presented in Table 3. The greatest decrease in thickness was observed in the fabrics which were laundered with the fabric softener added to the rinse, while dry cleaning had the least effect on fabric thickness.

Also, Table 3 shows that Blanket I, the 100% acrylic napped plain weave had a greater decrease in thickness than Blanket II, the 100% nylon fiber bonded to polyeurethane foam. There are two possible explanations for this. The fibers in Blanket II were bonded to a base material and were not as easily removed by agitation during cleaning (weight loss was not evaluated but it was observed that after washing and tumble drying, the lint filters in both machines were filled with fibers from Blanket I), or the fibers in Blanket I could more easily have been compacted together than those of Blanket II.

Table 3: Percentage Decrease in Fabric Thickness after Five Cleanings

Blanket No.	Cleaning Procedure	Percentage decrease
I	A	6.1 **
	B	16.5 **
	C	9.6 **
	D	4.3 **
II	A	6.6 **
	B	9.5 **
	C	5.7 **
	D	1.9 **

** Significant at 0.05 level

Dimensional Stability

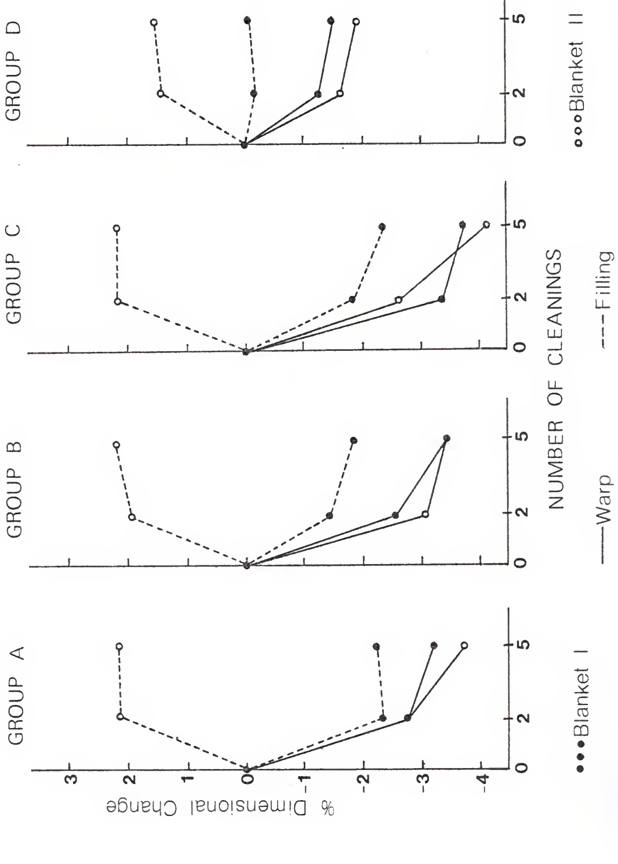
Figure 2 presents the effect of repeated launderings, with and without fabric softeners, and repeated dry cleanings on the dimensional stability of the two types of blankets. Since dimensional change can occur in both positive and negative directions, shrinkage is plotted as a negative number, while stretch is recorded as a positive number.

An analysis of variance (ANOVA) statistical test was performed on the percentage dimensional change means in both the warp and filling directions. The main effects, agian, were typw of material, cleaning procedure, and number of cleanings.

Warp Direction

Cleaning procedure and number of cleanings significantly affected dimensional stability in the warp direction. After cleanings, all four groups of specimens (i.e. Groups A, B, C, and D) showed

Fig. 2. The Effect of Cleaning on Dimensional Change (Note: Group A - washed with detergent alone; Group B - washed, softener added to rinse; Group C - washed, softener added to dryer; Group D - dry cleaned)


GROUP A
GROUP B
GROUP C
GROUP D
% Dimensional Change
3
2
1
0
-1
-2
-3
-4
0
2
5
NUMBER OF CLEANINGS
●●●Blanket I
—Warp
---Filling
○○○Blanket II

significant dimensional decreases (i.e. shrinkage) in the warpwise direction. Groups A, B, and C, those laundered and tumble dried with and without fabric softeners, shrank significantly more than the dry cleaned specimens, Group D. There was no significant difference among the groups laundered with and without fabric softeners, and laundering in general caused greater shrinkage than dry cleaning in the warp direction. As the number of cleanings increased, there was a progressive increase in shrinkage. In addition, the following two way interactions significantly affected the warpwise dimensional stability of the selected blankets: number of cleanings X cleaning procedure and type of material X number of cleanings.

Figure 2 illustrates that significant shrinkage occurred after two cleanings for all four cleaning procedure groups (i.e. Groups A, B, C, and D). Dry cleaning had less of an effect on dimensional change than laundering. Groups B and C, those in which fabric softeners were added, continued to show significant shrinkage with increased laundering, with Group C (i.e. fabric softener added to the dryer) having significantly greater shrinkage than Group B (i.e. softener added to the rinse). Thus, after five launderings, the fabric softener that was added to the dryer caused significantly higher shrinkage in the warp direction than the other cleaning procedures.

Filling Direction

Unlike in the warp direction, material type significantly affected fillingwise dimensional change. Blanket II exhibited positive dimensional change (i.e. stretch), while Blanket I exhibited negative change (i.e. shrinkage). In addition, the fillingwise shrinkage in Blanket I, occurred for all specimens in Groups A, B, C, and D. Similarly, the fillingwise stretching in Blanket II specimens occurred for all cleaning procedure groups. Within the cleaning groups for Blanket I, the dry cleaned specimens shrank significantly less than the laundered specimens. Within the cleaning procedure groups for Blanket II, the dry cleaned specimens exhibited less stretch than did the laundered specimens, however, the differences were non-significant. For the laundered Blanket I and Blanket II fabrics, the significant dimensional changes occurred after two cleanings and then leveled off. Blanket II, Group D specimens exhibited signifcant stretching after two dry cleanings but the shrinkage which occurred after two dry cleanings for Blanket I, Group D specimens was non-significant.

Table 4 shows the amount of percentage dimensional change that occurred after five cleanings. From this, the difference in warpwise and fillingwise change can be seen. Within both blanket fabrics, there was more shrinkage in the warp direction than in the filling direction. It is generally true of most fabrics that there be more shrinkage warpwise than fillingwise because of relaxation shrinkage.

Table 4: Percentage Dimensional Change after Five Cleanings

Blanket type	Cleaning Procedure	Percentage change Warp	 Filling
I	A	-3.83 **	-2.25 **
	B	-3.50 **	-1.93 **
	C	-4.17 **	-2.50 **
	D	-1.50 **	-0.08
II	A	-3.25 **	+2.08 **
	B	-3.50 **	+2.08 **
	C	-3.83 **	+2.08 **
	D	-2.00 **	+1.50 **

** Significant at the 0.05 level.

Air Permeability

Figure 3 illustrates the effects of laundering and dry cleaning on the air permeability of the two blanket fabrics tested. An analysis of variance statistical test was performed on the mean air permeability values obtained before and after two and five launderings and dry cleanings. The main effects in the analysis remained the same as discussed in previous ANOVA's.

Material and number of cleanings had significant effects on the air permeability of the blankets but cleaning procedure was a non-significant variable. Blanket I (100% acrylic, napped plain weave) was more permeable to air than Blanket II (100% nylon fiber bonded to polyeurethane foam). There was a significant decrease in air permeability after five launderings, with and without fabric softeners, and dry cleanings. In addition, the following second order interactions were significant: material X number of cleanings and number of cleanings X cleaning procedure.

Blanket I (100% acrylic) exhibited a decrease in air permeability as the number of cleanings increased; whereas, Blanket II (100% nylon) showed an increase. Significant changes in air permeability occurred after two launderings and dry cleanings in all four groups of specimens. In all cases, the amount of change was not significant between two and five launderings or dry cleanings. These results correlate somewhat with the results obtained for dimensional change. As a material shrinks, the fibers become more compact and thus allow less air to penetrate.

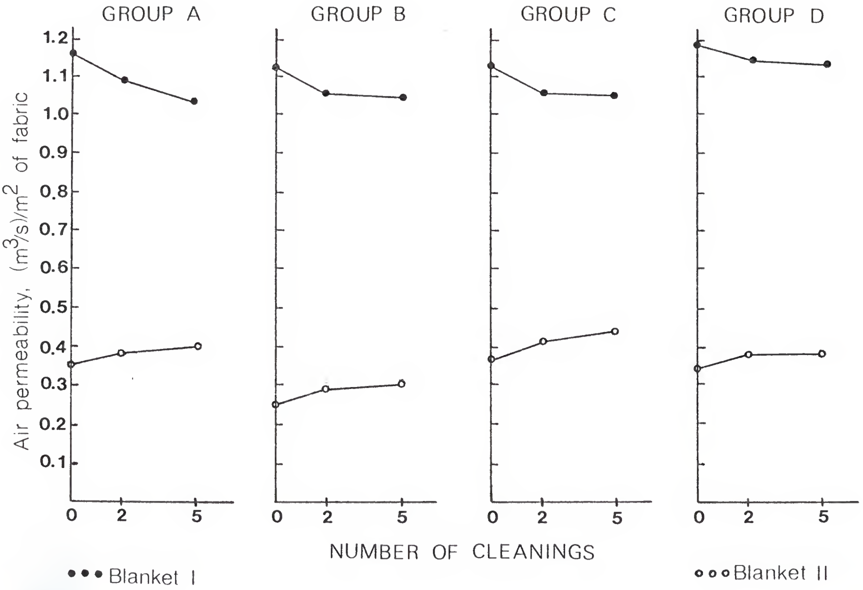
In an attempt to compare the different cleaning procedures and their effect on air permeability, it is helpful to look at percentage change after a total number of launderings and dry cleanings. The percentages given in Table 5 are averaged over the two blanket fabrics that were tested. As indicated, all four cleaning procedures caused significant decreases in air permeability. But, results also indicated that air permeability was decreased the most in Group A where the blankets were washed in detergent alone, whereas, dry cleaning had the least effect on air permeability. There was no significant difference between the effects of the two types of fabric softeners.

Table 5: Percentage Change in Air Permeability after Five Cleanings

Cleaning Procedure	Percentage Change
A	-6.0 **
B	-2.2 **
C	-2.2 **
D	-0.7 **

** Significant at the 0.05 level.

Fig. 3. The Effect of Cleaning on Air Permeability (Note: Group A - washed with detergent alone; Group B - washed, softener added to rinse; Group C - washed, softener added to dryer; Group D - dry cleaned)


GROUP A
GROUP B
GROUP C
GROUP D
Air permeability, (m³/s)/m² of fabric
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
5
NUMBER OF CLEANINGS
●●● Blanket I
○○○ Blanket II

Thermal Transmission

An analysis of variance (ANOVA) test was performed on the specific conductivity (k) values for the two blanket fabrics before and after subsequent cleanings. The mean specific conductivity values of the test fabrics are given in Tables 1 and 2. Intrinsic Clo values also were calculated. The type of blanket material was the only independent variable to have a significant effect on thermal conductivity. Cleaning procedure and number of cleanings were non-significant as well as all second and third order interactions.

Blanket I was significantly lower in thermal conductivity than Blanket II. Thermal insulation or resistance is the inverse of thermal transmittance or conductivity. In other studies (3,4,6,7,8,9), thickness and thermal insulation have been found to be directly related. As is true in this study, Blanket I (1005 acrylic) was slightly thicker and more insulative than Blanket II (100% nylon).

Thermal insulation also is dependent on the air permeability of a material. The results of the air permeability test, as illustrated in Figure 3, indicate that Blanket I was more permeable to air than Blanket II. Thermal insulation is dependent on the amount of air which is immobilized by the fabric. Therefore, the more permeable to air the fabric is, the more open the structure, thus allowing more air to be entrapped and increasing insulation.

The results of this study showed, therefore, that repeated launderings and dry cleanings will not substantially reduce the thermal insulative properties of blanket fabrics. In addition, the use of fabric softeners in laundering will not have detrimental effects on the thermal properties.

CONCLUSION

In this study, two blanket fabrics, one a woven 100% acrylic with a napped surface and the other, a 100% nylon fiber bonded to polyeurethane foam were subjected to repeated launderings, with and without fabric softeners and repeated dry cleanings to determine the effects of such treaments on their thermal insulative properties. Thickness was decreased by all four cleaning procedures. Dry cleaning had the least effect on thickness. Significant shrinkage occurred in the warp direction of both blanket fabrics and in the filling direction of the woven 100% acrylic blanket after two cleanings. There was significant stretch in the filling direction of the bonded 100% nylon blanket after two cleanings. Dimensional change declined after two cleanings. All four cleaning procedures showed significant dimensional change in all but the filling direction of the woven 100% acrylic blanket when dry cleaned. Changes in air permeability, like dimensional change, tended to occur between zero and two cleanings. Repeated cleaning had no significant effect on the thermal conductivity of the blanket fabrics that were tested. Therefore, thermal insulation was unaffected by repeated launderings and dry cleanings and by the use of fabric softeners.

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APPENDIX

Review of Literature

The human body is constantly exchanging heat with its enviroment to maintain its internal temperature of around 37° C. Clothing provides protection from excess heat loss from a warm body to a cool atmosphere. When the body is resting, it is producing less energy than when it is moving. Thus additional protection is required to prevent heat loss, especially during cold winter nights. It is important for the thermal insulative properties of blankets to be maintained throughout prolonged use and care. The purpose of this study was to compare the effects of home laundering and commercial dry cleaning on the thermal insulative properties of blankets. Within the area of home laundering, the effects of fabric softeners on thermal properties also was investigated.

Heat Transfer

Heat transfer takes place when the body procedes to maintain its homeostatic temperature. Heat is transferred by three methods; conduction, convection, and radiation. Heat transfer occurs when the temperature attempts to equalize between a hot body and a cool atmosphere. The addition of these three processes will give total heat transfer.

Conduction occurs when heat is transferred through direct contact. In fabrics, heat is lost by conduction through individual fibers. It has been found that in general, the denser the fabric, the greater the heat loss, owing to more fibers within a specific area. The "rate of heat flow by conduction per unit area temperature gradient" is referred to as the thermal conductivity of the material. Thermal conductivity per unit thickness is designated by the variable "k". The thermal conductivity of air is very low, thus air is a good insulator. It is the entrapped air or "dead air" spaces within blanket fabric that their insulating properties are attributed. A typical k value near 20° C for fiber-blanket insulation is 0.27 $\text{Btu}\cdot\text{in/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}$ (13).

Heat transfer through the circulation of liquids or gases is known as convection. Convection occurs when hot air (less dense) rises and at the same time cooler air moves in to fill the void. This is a continuous cycle. This is also illustrated with water. As water becomes warmer (less dense), it turns to steam and rises. Often, especially with natural fibers, there are tiny molecules of water entrapped within the fabric. This moisture allows for heat transfer from the warm side of the fabric to the cooler side by the process of convection. Also, circulation of the air entrapped between the fibers permits heat transfer by convection (13).

Whereas conduction and convection require a medium for heat transfer, radiation occurs without one. Heat is transferred from a hot object to a cool object by means of electro-magnetic radiation, similar to that of light (5). When heat passes through a material, part of the heat is absorbed which can then be reflected or transmitted. Radiation travels in straight lines and can be reflected, absorbed, or transmitted by a substance. Heat transfer by radiation occurs when energy from the sun or other radiating source falls on the fabric, is absorbed, and warms the cloth (3).

There are two types of physical units used to express the thermal properties of clothing, either transmission or conductance, and thermal resistance or insulation units. The two are inversely related. Resistance units are preferred, as they can be added together to give the total resistance offered by layers of fabric (3). However, this is often invalid, as some fabrics afford greater resistance with the addition of other fabrics. For instance, a flannel lined wind breaker would give more resistance in wind, than the sum of their individual R-values would reveal (1).

Thermal transmission is the over-all heat transfer through a system at a steady state. Thermal conductivity is the rate of heat flow through a material by conduction per unit area per temperature gradient (13). Rees (8) described thermal conductivity of textile fabric as "the thermal conductivity of a disperse system consisting of textile substance and air, and not that of a massive substance, say of cellulose." The symbol U_1 is used to designate the thermal transmittance of a test specimen and air. When using a hot-plate, it is calculated by dividing the power loss from the test plate in Btu/h by the area of the test plate in square feet times the difference in temperatures between the test plate and air in degrees Farenheit. The bare plate transmittance, U_{bp}, is calculated in the same way. The intrinsic thermal transmittance coefficient of the fabric alone, U_2, is calculated as the product of U_{bp} and U_1 divided by their difference (1).

The resistance to the flow of heat is referred to as thermal insulation. In addition to the insulation offered by clothing, there is a layer of ambient air on the surface of the fabric. Since air is a good insulator, more insulation is afforded in still air than in moving air. The difference in temperatures between two surfaces compared to the flow of heat per unit area is equivalent to the thermal insulation (4).

The higher the R value, the better the insulator. The intrinsic resistance (R) coefficient is the reciprocal of the intrinsic transmittance coefficient (1). Clo is a thermal insulation unit developed by Gagge, Burton and Bazette (4) to determine the amount of insulation required to maintain skin temperature at 92-96°F in a normally ventilated room (air movement 20 ft/min or 10 cm/sec at a temperature of 70° F (21° C) and less than 50% r.h.). According to Pierce and Rees (7) thermal resistance depends upon the amount of air immobilized by the fabric.

Factors Affecting Thermal Transmittance

It is true that fibers themselves are conductors of heat. However, fiber constituents have little to do with the thermal insulative value of the fabric. Thermal insulation is more dependent on the structure of the fabric (7).

According to Fourt and Harris (3), compressional resilience is most desirable for thick insulating materials, however, the main factor in insulating value is thickness.

Speakman and Chamberlain (15) found that weave structure had an indirect effect on the thermal conductivity of fabric, in that it would alter thickness and density of the fabric. According to Speakman and Chamberlain, specific conductivity is dependent on thickness, density, and the nature of the constituent fibers. The effect of density on specific conductivity is relatively small, but as density increases, so does conductivity. Also, a fibrous layer on the surface or a fluffy surface tends to lower conductivity.

Marsh (6) also found that thickness was the predominant factor in determining the thermal insulative value of fabrics. However, no direct relationship was found between thermal insulating value and density, but less dense fabrics tended to show a higher thermal insulating value than others. Also, a slight increase in thermal insulating value was detected with an increase in weight.

In 1858, Colier, Professor of Military Hygiene in Paris, performed experiments on clothing fabrics. He found that as liquid water was absorbed by fabirc, thermal insulation decreased. But when water vapor was absorbed into the fabric, heat was released (9). Fourt and Harris (3) also found that the absorption of liquid water decreased thermal insulation of clothing. The fabric tended to collapse and cling to the skin, thus reducing the insulating affect of the air layer.

In a study done by Rees (8) it was concluded that increased humidity increases heat loss, however, such changes in humidity are small with actual wear. Evaporation from the insulated body would be the major source of change.

According to Bogarty, Hollies, and Harris (2) not only does fabric thickness affect thermal conductivity, but so does fiber arrangement. By this it is meant that the fibers lie parallel and perpendicular to the fabric surface. For smooth surfaced fabrics, those with fibers parallel to the surface, an increase in pressure yielded an increase in conductivity. This being due to increased density since the fiber arrangement was unaltered. However, for fuzzy surfaced fabrics, those with fibers perpendicular to the surface, an increase in pressure decreased conductivity. As pressure was applied, the perpendicular fibers were bent over, allowing air to be entrapped between the fibers, thus reducing conductivity.

Insulative Properties of Blankets

It is desirable for blankets to afford warmth without weight. This is achieved by entrapped air between the fibers. Air is a very poor conductor of heat, thus insulation is increased as porosity increases as long as the air remains still within the fabric structure. Consequently, the purpose of a raised or napped surface on a blanket or a cellular structure within a blanket is to entrap air for insulation (16).

According to Taylor (16) of the Shirley Institute, a tog value of about 9 is required for bed coverings in a cold bedroom in the winter. A tog is a thermal resistance unit less than a clo. This may be achieved by using four or five napped blankets at a weight of 4 lbs/yd^2 or by a similar number of cellular blankets at a weight of about 2 lbs/yd^2. There is more air incorporated within cellular blankets, thus the same about of insulation is achieved with less weight.

In a study done by Schiefer, Stevens, Mack, and Boyland (12) on household blankets, it was found that laundering had little effect on thermal transmission. Shrinkage, due to laundering caused an increase in thickness while decreasing compressibility, two factors which affect thermal transmission. The two changes tended to compensate each other, yeilding no apparent change in conductivity. There also was little difference between the effects of laundering and dry cleaning. These tests were done on over 150 blankets of various materials and thicknesses. The only effect observed due to the fiber composition was due to differences in compressional resilience afforded by the different fibers. Wool yielded greater compressional resilience than cotton or rayon. As a result of comparing blankets of various materials and thicknesses and knit underwear, Schiefer et al. found that thermal resistance could be accurately calculated knowing the thickness of the fabric.

Fabric Softeners

Fabric softeners are effective as anti-static agents, especially on hydrophobic materials. Moisture within natural fibers serve as a conductance material, grounding any electrical charge that may have resulted from the rubbing of the fabric against itself. Fabric softeners increase the moisture absorbency of man-made, hydrophobic fabrics. Quaternary salts are the primary component of fabric softeners. The hydrophillic portion of the quaternary salts coats the fabric, thus increasing the fabrics affinity for water (17).

Methods of Evaluating Thermal Transmittance

A variety of instruments have been used for evaluating thermal resistance and thermal transmittance. The disc or plate method for example, measures the flow of heat through a fabric between two plates of different temperatures. The Fitch thermal conductivity apparatus is an example of this method in which the fabric is placed between a beaker of water and a heat senser plate. The constant temperature method measures the amount of energy required to maintain a constant temperature above that of the surrounding air. In this method, a body may be wrapped in fabric to be tested and allowed to cool. The rate of cooling is measured by recording the time it takes to cool to a certain temperature. The hot plate method involves a guarded hot plate apparatus. The test plate is surrounded by a guard ring and underneath by a bottom plate to prevent heat loss from the plate. The test specimen is placed over the test plate and guard ring and the rate of heat transfer through the fabric is measured. This apparatus must be used in a controlled enviromental test chamber (14). A more recent development in the evaluation of heat transfer through clothing is the copper manikin. This is a life sized electrically heated black colored body. Since the manikin is dressed, this method takes into account the air spaces between the body and its clothing as a factor of insulation. Clo values can be calculated using this method.

Of the above methods, Schiefer et al. (11) used the hot plate method in their study on household blankets. The copper manikin has been used to evaluate thermal resistance afforded by clothing ensembles (12). Sleeping bags also have successfully been evaluated using the copper manikin (12). Blankets, also could be evaluated using this method if a bag was constructed using the blanket fabric to cover the manikin or the manikin could be be placed on a mattress with covers over it to simulate a body sleeping.

Calibration of the Guarded Hot/Cold Plate

The guarded hot/cold plate that was used in this study was constructed at Kansas State University for the Department of Clothing, Textiles and Interior Design in accordance to the specifications given in ASTM D 1518: Standard Test Method for Thermal Transmittance of Textile Fabric and Batting Between Guarded Hot-Plate and Cool Atmosphere. The cold plate feature was included to increase the versatility of the testing instrument. The cold-plate will allow for studies to be performed that simulate material against a cold floor or wall. The guarded hot/cold plate is housed in an 8 x 10 ft. Sherer enviromentally controlled test chamber at the Kansas State Institute for Enviromental Research, Manhattan, Kansas.

Before the instrument was used to test unknown materials, it was first calibrated. Prior to heating, the hot-plate was allowed to reach equilibrium with the conditions of the test chamber. Theoretically, all thermistors within and around the instrument should all be at room temperature. However, there are slight differences between pairs of thermistors, whose differences later are used in the calculations for thermal transmittance. Therefore, correction factors were determined at this point and subtracted from the differences later. Figure A-1 is a simplified illustration of the guarded hot/cold plate, showing the location of the thermistors within the test plate.

$\bar{\Delta}t^c$ is the average of the corrected differences between thermistors 02 and 03 and thermistors 06 and 07. $\bar{\Delta}T^c$ is the corrected difference between the air temperature 20" above the test plate and the mean temperature of thermistors 03 and 07.

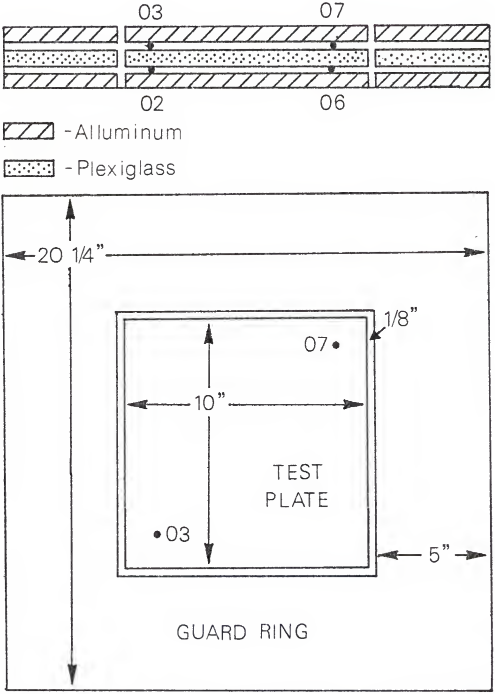

Fig. A-1. Location of Thermistors Within the Test Plate

The following corection factors were determined for this study:

Between thermistors 02 and 03: -0.111

Between thermistors 06 and 07: -0.085

Another correction factor also was determined between the air temperature 20" above the test plate and the average temperature of the test plate (mean of thermistors 03 and 07). The correction term for this was +0.140.

A 0.527 inch thick fiberglass insulation board, obtained from the National Bureau of Standards was used to calibrate the instrument. With the fiberglass standard, N.B.S. also provided Formula A-1 of known variables to calculate the thermal conductivity (k) of the standard. The only unknown variable was the temperature of the hot plate being used. The calculation are presented below:

$$k = A_0 + (A_1 \text{ X rho}) + (A_2 \text{ X alpha}^3) \qquad \text{(A-1)}$$

where: rho = bulk density kg/m^3

$$\text{alpha} = \frac{\text{mean temperature } {}^{\circ}C + 273}{100}$$

A_0 = 0.017210

A_1 = 0.00003839

A_2 = 0.0003892

mean temperature of hot-plate = 35.65° C

bulk density of fiberglass standard = 120.46 kg/m^3

This formula yeilds a k value in Watts/meter/$^{\circ}$K. The test method uses k in Btu·in/h·ft^{2}·$^{\circ}$F which is easily obtained by dividing W/m/$^{\circ}$K by 0.1441. Thus, k = 0.2310 Btu·in/h·ft^{2}·$^{\circ}$F. Knowing the thickness of the fiberglass standard, a thermal transmittance value can be obtained by dividing k by 0.527 in. (thickness measured at 0.01 psi). This is illustrated by Formula A-2.

$$U_2 = k/\text{thickness} \qquad \text{(A-2)}$$

$$U_2 = 0.2310/0.527 = 0.4383 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}$$

At this point, the thermal conductivity of the fiberglass standard is known. It is possible, now, to work backwards to determine the amount of power loss from the test plate. Formula A-3 is used to calculate the constant B, which will be used to determine power loss in all other calculations for thermal transmittance.

$$B = \frac{U_2}{\bar{\Delta}t_1{}^c/(A \times \Delta T_1{}^c)} - \frac{U_2}{\bar{\Delta}t_{bp}{}^c/(A \times \Delta T_{bp}{}^c)} \qquad \text{(A-3)}$$

Where: U_2 = thermal transmittance of the fiberglass standard.

$\bar{\Delta}t_1{}^c$ = average corrected difference in temperatures (°F) above and below the plexiglass within the hot-plate with the fiberglass standard on the hot-plate.

$\Delta T_1{}^c$ = average corrected difference in temperatures (°F) of the hot-plate and the air 20" above the hot-plate with the fiberglass standard on the hot-plate.

$\bar{\Delta}t_{bp}{}^c$ = average corrected difference in temperatures (°F) above and below the plexiglass within the hot-plate with nothing on the hot-plate.

$\Delta T_{bp}{}^c$ = average corrected difference in temperatures (°F) of the hot-plate and the air 20" above the hot-plate with nothing on the hot-plate.

A = area of test plate, ft^2.

The following values were used in Formula A-3 to obtain the constant B:

$$U_2 = 0.4282 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}$$

$$\bar{\Delta}t_1{}^c = 1.6704^\circ \text{ F}$$

$$\Delta T_1{}^c = 25.5465^\circ \text{ F}$$

$$\bar{\Delta}t_{bp}{}^c = 3.1338^\circ \text{ F}$$

$$\Delta T_{bp}{}^c = 18.9468^\circ \text{ F}$$

$$A = 0.694 \text{ ft}^2$$

$$\therefore \; B = 2.7480 \text{ Btu/h}\cdot{}^\circ\text{F}$$

Using the above values, the constant U_{bp} (thermal transmittance of the bare plate) is also calculated, Formula A-4.

$$U_{bp} = B \cdot \bar{\Delta}t_{bp}{}^c/(A \text{ X } \Delta T_{bp}{}^c) \qquad \text{(A-4)}$$

$$U_{bp} = 0.6549 \text{ Btu/h}\cdot\text{ft}^2\cdot{}^\circ\text{F}$$

Sample Calculations for the Two Blanket Fabrics

Direct readings from hot plate thermistors for Blanket I and Blanket II are presented in Tables A-1 and A-2, respectively. Also included in the tables are the temperature differences across the plexiglass within the hot plate. These values in turn are used to calculate the average corrected difference in temperatures across the plexiglass.

BLANKET I, 100% acrylic, napped weave.

Table A-1: Readings From Hot Plate for Blanket I

thermistor no.	temperature °C	Δt_1 °C	$\Delta t_1{}^c$ °C
02	35.987	1.149	1.260
03	34.838		
06	36.122	1.237	1.322
07	34.885		

Average temperature of the air 20" above test plate:

$$\bar{T}_a = 22.1660^\circ \text{ C}$$

Average temperature of the test plate:

$$\bar{T}_p = 34.8615^\circ \text{ C}$$

Corrected difference between air temperature and plate temperature:

$$\Delta T_1{}^c = 12.5555^\circ \text{ C or } 22.5999^\circ \text{ F}$$

Average corrected difference in temperature across plexiglass within the test plate:

$$\bar{\Delta}t_1^{\,c} = 1.2910^\circ\ \mathrm{C} \quad \text{or} \quad 2.3238^\circ\ \mathrm{F}$$

Bare plate transmittance coefficient:

$$U_{bp} = 0.6549\ \mathrm{Btu/h{\cdot}ft^2{\cdot}{}^\circ F}$$

Thickness:

$$th = 0.18\ \mathrm{in.}$$

Combined thermal transmittance coefficient of the specimen plus air:

$$U_1 = B{\cdot}\bar{\Delta}t_1^{\,c}/(A \times \Delta T_1^{\,c}) = 0.4071\ \mathrm{Btu/h{\cdot}ft^2{\cdot}{}^\circ F}$$

Intrinsic transmittance coefficient of the fabric alone:

$$U_2 = (U_{bp} \times U_1)/(U_{bp} - U_1) = 1.0759\ \mathrm{Btu/h{\cdot}ft^2{\cdot}{}^\circ F}$$

Specific conductivity coefficient for a unit thickness:

$$k = U_2 \times th = 0.1937\ \mathrm{Btu{\cdot}in/h{\cdot}ft^2{\cdot}{}^\circ F}$$

BLANKET II, 100% nylon fiber bonded to polyeurethane foam.

Table A-2: Readings From Hot Plate for Blanket II

thermistor no.	temperature °C	t_1 °C	t_1^c °C
02	36.167	1.267	1.378
03	34.900		
06	36.342	1.404	1.489
07	34.938		

Average temperature of the air 20" above test plate:

$$\bar{T}_a = 22.5435^\circ \text{ C}$$

Average temperature of the test plate:

$$\bar{T}_p = 34.919^\circ \text{ C}$$

Corrected difference between air temperature and plate temperature:

$$\Delta T_1{}^c = 12.3255^\circ \text{ C} \quad \text{or} \quad 22.0239^\circ \text{ F}$$

Average corrected difference in temperature across plexiglass within the test plate:

$$\bar{\Delta} t_1{}^c = 1.4335^\circ \text{ C} \quad 02 \quad 2.5803^\circ \text{ F}$$

Bare plate transmittance coefficient:

$$U_{bp} = 0.6704 \text{ Btu/h.ft}^2.{}^\circ\text{F}$$

Thickness:

$$th = 0.17 \text{ in.}$$

Combined thermal transmittance coefficient of the specimen plus air:

$$U_1 = B\cdot\bar{\Delta} t_1{}^c/(A \text{ X } \Delta T_1{}^c) = 0.4639 \text{ Btu/h}\cdot\text{ft}^2.{}^\circ\text{F}$$

Intrinsic transmittance coefficient of the fabric alone:

$$U_2 = (U_{bp} \text{ X } U_1)/(U_{bp} - U_1) = 1.5906 \text{ Btu/h}\cdot\text{ft}^2.{}^\circ\text{F}$$

Specific conductivity for a unit thickness:

$$k = U_2 \text{ X } th = 0.2704 \text{ Btu}\cdot\text{in/h}\cdot\text{ft}^2.{}^\circ\text{F}$$

Analysis of Variance Tables

An analysis of variance procedure of split-split-plot experiment was performed on the data obtained from thickness, dimensional stability in both the warp and filling directions, air permeability, and specific conductivity (k), before and after subsequent laundering and dry cleaning. The results are presented in Tables A-3, A-4, A-5, A-6, and A-7. The level of confidence established was 0.05.

The experiment was set up so that the initial readings were taken on the specimens before any laundering or dry cleaning was performed. The specimens were then subjected to two cleaning procedures and evaluated accordingly. And then again after a total of five cleaning procedures. Each sample cell was an average of three specimens. The independent variables were number of cleanings (3 levels), type of material (2 levels), and cleaning procedure (4 levels). There were two replications carried out. Replica and sample number were used in the analysis but not as main effects because the specimens from each blanket type were obtained from the same bolts of material. The dependent variables were thickness; dimensional stability, warpwise and fillingwise; air permeability; and thermal conductivity.

Table A-3: Analysis of Variance of Split-Split-Plot Experiment on Fabric Thickness

Source of Variation	SS	d.f.	MS	F
Main Plots:				
Material (M)	0.02047284	1	0.02047284	25.85[**]
Error (Replica(Material))	0.00158407	1	0.00079204	
Sub Plots:				
Cleaning Procedure (P)	0.00321897	3	0.00107299	21.78[**]
M X P	0.00010241	3	0.00003414	0.69
Error (Sample(M X P X R))	0.00187188	38	0.00004926	
Sub-Sub-Plots:				
Number of Cleanings (C)	0.00418172	2	0.00209086	195.74[**]
M X C	0.00058372	2	0.00029186	27.32[**]
C X P	0.00118656	6	0.00019776	18.51[**]
M X C X P	0.00018744	6	0.00003124	2.92[**]
Error	0.00085456	80	0.00001068	

[**] Significant at 0.05 level.

Table A-4: Analysis of Variance of Split-Split-Plot Experiment on Percentage Dimensional Change in the Warp Direction

Source of Variation	SS	d.f.	MS	F
Main Plots:				
Material (M)	0.3906	1	0.3906	0.53
Error (Replica(Material))	1.4618	2	0.7259	
Sub Plots:				
Cleaning Procedure (P)	35.0329	3	11.6776	31.21^{**}
M X P	1.2135	3	0.4045	1.08
Error (Sample(M X P X R))	14.2187	38	0.3741	
Sub-Sub-Plots:				
Number of Cleanings (C)	272.6354	2	136.3177	585.96^{**}
M X C	1.8229	2	0.9114	3.92^{**}
C X P	18.9618	6	3.1603	13.58^{**}
M X C X P	1.6354	6	0.2725	1.17
Error	18.6111	80	0.2326	

**Significant at the 0.05 level.

Table A-5: Analysis of Variance of Split-Split-Plot Experiment on Percentage Dimensional Change in the Filling Direction

Source of Variation	SS	d.f.	MS	F
Main Plots:				
Material (M)	196.2334	1	196.2334	188.12**
Error (Replica(Material))	2.0862	2	1.0431	
Sub Plots:				
Cleaning Procedure (P)	6.2029	3	2.0676	5.88**
M X P	20.7502	3	6.9167	19.68**
Error (Sample(M X P X R))	13.3554	38	0.3514	
Sub-Sub-Plots:				
Number of Cleanings (C)	0.8709	2	0.4354	1.92
M X C	98.5043	2	49.2521	216.69**
C X P	3.7018	6	0.6169	2.71**
M X C X P	11.0795	6	1.8465	8.12**
Error	18.1833	80	0.2272	

**Significant at the 0.05 level.

Table A-6: Analysis of Variance of Split-Split-Plot Experiment on Air Permeability

Source of Variation	SS	d.f.	MS	F
Main Plots:				
Material (M)	716,353.4617	1	716,353.4617	1,172.24**
Error (Replica(Material))	1,222.1996	2	611.0998	
Sub Plots:				
Cleaning Procedure (P)	326.8883	3	1,089.9628	1.56
M X P	2,531.6932	3	843.8977	1.21
Error (Sample(M X P X R))	26,467.8481	38	696.5223	
Sub-Sub-Plots:				
Number of Cleanings (C)	374.0392	2	187.0196	17.05**
M X C	5,078.7154	2	2,539.3577	231.48**
C X P	239.1485	6	39.8581	3.63**
M X C X P	278.2463	6	45.3743	4.23**
Error	877.5904	80	10.9699	

**Significant at the 0.05 level.

Table A-7: Analysis of Variance of Split-Split-Plot Experiment on Thermal Conductivity (k)

Source of Variation	SS	d.f.	MS	F
Main Plots:				
Material (M)	0.3601	1	0.3601	366.29**
Error (Replica(Material))	0.0020	2	0.0010	
Sub Plots:				
Cleaning Procedure (P)	0.0066	3	0.0022	1.69
M X P	0.0099	3	0.0033	2.56
Error (Sample(M X P X R))	0.0491	38	0.0012	
Sub-Sub-Plots:				
Number of Cleanings (C)	0.0039	2	0.0019	1.63
M X C	0.0030	2	0.0015	1.25
C X P	0.0048	6	0.0008	0.66
M X C X P	0.0090	6	0.0015	1.24
Error	0.0965	80	0.0012	

** Significant at the 0.05 level.

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THE EFFECTS OF LAUNDERING WITH AND WITHOUT FABRIC SOFTENERS AND DRY CLEANING ON THE THERMAL PROPERTIES OF BLANKETS

by

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AN ABSTRACT OF A MASTER'S THESIS

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As an essential article in every home, blankets are primarily used for warmth. It is important to maintain this property throughout the normal life of the blanket. Through subsequent laundering or dry cleaning, these properties are frequently decreased. The purpose of this study was to evaluate the effects of laundering, with and without fabric softeners and dry cleaning on the thermal properties of blankets.

The blankets selected for this study were chosen on the basis that they were two of the most common blankets available to the consumer today. One blanket fabric was a 100% acrylic napped plain weave. The other blanket fabric was constructed of two layers of 100% nylon fibers bonded to polyeurethane foam, sandwiched together by a scrim. The softeners used in this study included one which was added to the final rinse in laundering and one which was added to the dryer. Before and after two and five launderings and dry cleanings, the samples were evaluated instrumentally for changes in thickness, air permeability, dimensional stability, and thermal transmittance. An analysis of variance procedure of a split-split-plot experiment was applied to the data obtained for each evaluation to determine significant differences among the independent variables of type of material, cleaning procedure, and number of cleanings.

Thickness was measured under 0.07 k N/m^2 (0.01 psi) using a Frazier Compressometer following ASTM Designation D 1518. Thickness was significantly decreased after repeated launderings and dry cleanings. The cleaning procedure used, was also significant. Dry cleaning had the least effect, while the fabric softener added to the rinse cycle had the most effect on thickness.

The Frazier Air Permeability Testing Machine was used to evaluate air permeability according to ASTM Designation D737. Air permeability was measured by the volume of air flowing in unit time through a unit area of the material when the pressure difference across one thickness of the material is 127 pascals (0.5 inches of water). Significant change in air permeability occurred between zero and two launderings and dry cleanings in both fabrics. However, it increased for the nylon fabric and decreased for the acrylic material. The method of cleaning was nonsignificant.

The procedure in ASTM Designation D2724 was followed for evaluating dimensional change. Again, as with air permeability, significant change occurred between zero and two launderings and dry cleanings. Dry cleaning had the least amount of effect on dimensional change, however it was still significant.

A guarded hot/cold plate was used to evaluate the thermal transmission of the test fabrics according to ASTM Designation D1518. Thermal transmission was measured by the rate of heat loss through the fabric into the air by recording the amount of energy required to maintain the source at a constant temperature. There was no significant change in thermal conductivity after repeated launderings, with and without fabric softeners or after repeated dry cleanings.