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Title THERMAL INSULATION VALUES OF WOOL AND ACRYLIC BLANKETS BEFORE AND AFTER LAUNDERING

Abstract approved ______________________

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Twelve Acrilan acrylic, twelve Orlon acrylic, and twelve wool blankets were studied to determine the effect of laundering on thermal insulation value. The thirty-six blankets used in this study were selected and purchased by Florence Petzel for use in the study of the effects of maintenance on wool and acrylic blankets.

Specified sections of each of the blankets were laundered zero, one, five or ten times using a soak wash method. Cutting diagrams were then developed for each blanket section. Seven hundred twenty warmth tests specimens, each measuring five inches square, were prepared at the time of Petzel's study. They were kept under constant temperature before the testing began and throughout the testing procedures. The laboratory tests included a thickness reading on the Compressometer and a warmth determination using the Cenco-Fitch instrument.
The data from the warmth study is discussed in two parts. The thickness measurements and thermal conductivity values for each laundry interval are noted first. This is followed by a discussion of the significance of the relationship of thickness to warmth. The findings show a loss in the thickness of the Orlon acrylic and Acrilan acrylic blankets during laundering caused by matting and/or a loss of fibers. Conversely, the wool blankets gained continuously in thickness due to shrinkage. The thickest blankets had the lowest thermal conductivity values and were the best insulators; the thinnest blankets had the largest thermal conductivity values and had the least insulation value. This emphasizes the importance of the retention of thickness for the maintenance of warmth.

There was not a significant difference in the amount of heat that was transmitted by the Orlon acrylic, Acrilan acrylic or wool blankets. This implies that warmth is dependent upon the thickness of a blanket and the retention of that thickness rather than upon the fiber content. An increase in insulation value was generally followed by a decrease in insulation value if the blanket lost thickness. The insulation value improved if the blanket shrank and became more compact. However, there is a point at which compactness is detrimental to warmth because of the reduction of vital air spaces.
It was concluded that the warmth of a blanket is controlled by the thickness of the blanket and its ability to retain that thickness with laundering. It was further concluded that a thickness reading which is interpreted along with data on dimensional stability, yarn count, weight, and breaking strength would be sufficient to predict warmth for consumer purposes and information. It was recommended that subjective testing with individuals be included in future evaluations for more meaningful information. The best guide for the selection of a blanket still appears to be the brand name of a reputable manufacturer and a business firm to which the blanket may be returned if its performance is not satisfactory. One could expect to find warm blankets made from any fiber material provided the blanket is suitably woven and sufficiently thick.
THERMAL INSULATION VALUES OF WOOL AND ACRYLIC BLANKETS BEFORE AND AFTER LAUNDERING

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THERMAL INSULATION VALUES OF WOOL AND ACRYLIC BLANKETS BEFORE AND AFTER LAUNDERING

INTRODUCTION

The development of man-made fibers by industry has served to complicate the purchasing of textiles in apparel and home furnishings. "There has been an over emphasis and an exaggeration on both the national and local level of the virtues of fibers per se that tends to provide a distorted picture regarding the end use" (57, p. 54). The problem for industry is to efficiently, effectively, and creatively convert the fiber properties into an end result that will give the greatest value to the consumer. One home furnishing item that is frequently used by every consumer in this country is a blanket. The major reason for purchasing a blanket is to provide warmth while the body is inactive, and the blanket accomplishes this by slowing down the passage of heat from the body. The consumer formerly had a choice of cotton or wool fiber content when purchasing a blanket. "The acrylic blankets, however, have largely replaced the woolen ones on the market" (53, p. 188). The laundering procedures for cotton and wool blankets were generally known by the consumer. Whereas, the effects of the maintenance upon acrylic blankets have not been completely defined.

Blankets are classified as "broad woven goods" by the Bureau of the Census (54, p. 199). Fourteen million linear yards of woolen
and worsted broad woven goods were produced during 1959 and 1960. During the same period, 118 million linear yards were woven of man-made fibers. These fibers included rayon, acetate, nylon, polyester, glass, and acrylics (54, p. 198). The shipments of acrylic and modacrylic fiber within the United States have risen from 65 million pounds in 1956 to 124 million pounds in 1961 (48, p. 29). Blankets are one of the principal outlets for acrylics in the United States (48, p. 30). Possibly an influencing factor in this increased use of acrylics is the ease of care that is offered by these fibers. Blankets that are made from acrylic fibers are advertised as machine washable and dryable, shrink resistant, moth and mildew resistant, non-allergenic, and as offering warmth without weight (4, p. 56).

This study was initiated to provide information on the effects of maintenance upon the thermal insulation values of wool and acrylic blankets. Ten launderings were chosen to represent approximately the total number of laundering treatments that would be given to a blanket during its lifetime of use. The determination of the effect that maintenance has upon the warmth of wool and acrylic blankets made it necessary first to measure the change in the thickness that was caused by laundering. A specific objective was to determine whether or not the original blankets were comparable in their warmth characteristics and if they retained their warmth
after laundering. The information obtained from this study should be helpful to the consumer who is interested in selecting the most satisfactory blanket for the least expenditure.
REVIEW OF THE LITERATURE

Fabrics vary in the amount of heat that passes through them. The passage of heat, known as heat transmission, is dependent upon the mass, temperature, and specific heat of the fabric. Schwarz (49, p. 564) states that heat must be considered as a form of vibrational energy, as is light. Its wavelength range lies further up the scale than that for visible light and begins with what is known as infra-red radiation.

Heat may be transferred from one place to another by any one or a combination of three ways: conductance, convection, and radiation. There is a similarity between fabric behavior and ordinary building materials in their radiation, convection and conduction of heat, according to Winston and Backer (60, p. 62).

Radiation is largely a surface phenomenon. The flow of energy tends to travel in straight lines. Schwarz (49, p. 565) theorizes that the more broken the path along which the energy travels, as affected by the structure of the fabric, the more difficult the passage will be and a lesser amount of heat will be transmitted.

Convection refers to the transfer of heat in a mobile medium by expansion and the accompanying circulation of the medium. Schwarz (49, p. 564) notes that much of the heat transmitted
through fabrics in moving air takes place by convection.

Conduction describes the flow of heat through a solid material with the energy transfer taking place between the molecules themselves. Winston and Backer (60, p. 62) report that "heat flow of this nature is proportional to the temperature drop across the material and to the reciprocal of the thickness." Schwarz (49, p. 564) states that the term conductivity, when used in relation to fabrics, refers to the transfer of heat by a combination of conduction, radiation, and convection. Rees (42, p. T149) defines the thermal conductivity of textiles as the heat transmitted by a disperse system consisting of textile substance and air.

Brown (10, p. 6) recommends the use of a coefficient, which includes all methods of heat transfer, to evaluate the heat transmittance of a fabric. The constant for a given material is called the "coefficient of heat transmission." This is taken to be the number of calories per centimeter, per second, per degree centigrade. It is also called the coefficient of thermal conductivity and is usually represented for brevity by the letter "k". The conductance of a material is defined as the number of calories per square centimeter, per second, per degree centigrade, and its reciprocal is known as the resistance. The resistance can be considered a measure of the insulating power of the material. The
thermal insulation value of the blanket, as the author uses it, is
the ability of a specimen to resist the passage of heat.

The conductance of materials differs. Schwarz (49, p. 637)
points out that textile fibers are poor conductors of heat due to the
inclusion of large amounts of air and the lack of dense chemical
structure. Air is considered to be a poor conductor of heat.
Skinkle (50, p. 110) reports that the insulation value of a fabric
depends largely upon the number, size, and arrangement of its air
spaces. Aelion (2, p. 51) uses the term "porosity" to designate
the percentage of air space in a fabric and the term "permeability"
to define the ability of the fabric to allow a gas or vapor to pass
through it. He also states that porosity is a measure of density
which includes thickness and weight (2, p. 135). "Thermal resis-
tance is the ratio of the temperature difference to the heat flow
per unit area between two parallel isothermal planes," according
to Pierce and Rees (40, p. T182). Bogaty, Hollies and Harris (9,
p. 448) noted that better thermal resistance may be achieved by
the use of low conductance fibers and a mechanically stable ar-
rangement of fibers with low bulk density, which are parallel to
the surface. The overall thermal conductivity, as used in this pa-
per, is the rate of flow of heat by all possible modes across a unit
area of the material under a unit of the temperature at a specific
rate measured by a unit of time.

The terminology used in the literature evaluating the heat retention of blankets makes it difficult to transpose findings from one study to another. Marsh (29, p.T255) used the thermal insulation value "TIV" and explains it as the heat required to maintain the temperature of a heated surface when it is covered with a textile compared to that required to maintain the uncovered control surface. Another term, referred to as the Thermally Effective Specific Volume "TESV" by Pierce and Rees (40, p. T187), involves the ratio of the equivalent air thickness to the weight per unit area as a significant measure of thermal efficiency. Two other units which describe the resistance to the flow of heat are the "tog" and "clo." The tog was proposed by Pierce and Rees (40, p. T183) in 1946 and is considered to be one tenth of the ratio of the temperature difference in degrees centigrade to the heat flow in watts per square meter. The clo used by Gagge, Burton and Bazett (21, p. 428) is based upon the amount of insulation that would allow the passage of one calorie per square meter per hour with a temperature gradient of 0.18 degrees centigrade between the two surfaces.

Three common methods are used to measure the thermal insulation value of fabrics according to Skinkle (50, p. 97). They
are the disc or plate method, the cooling method and the constant temperature method. In the disc or plate method the fabric is held between two plates at different temperatures and the rate of flow of the heat through the fabric is measured. There should be sufficient pressure between the plates to assure good thermal contact without distorting the fabrics. In a recent investigation by Bogaty, Hollies and Harris (9, p. 446) it was shown that plate separations corresponding to fabric thickness under the pressure range of 0.002 to 1.0 pounds per square inch would not greatly alter thermal conductivity of a rough surfaced fabric. The results obtained by the disc method indicate the thermal conductivity of the fabric under a specific pressure, which should be stated.

Wing and Monego (59, p. 30) indicated that the Cenco-Fitch instrument measures dry thermal insulation. This may be defined as a rate-of-temperature-change measuring instrument. Because the heat receiver of the Cenco-Fitch instrument is made of a known mass of copper of a known specific heat, its change in temperature will measure the amount of heat received or lost. Since the heat could only have passed through a particular fabric under test, it is possible to measure the amount of heat that flows through the fabric in a given time. The instrument measures the conductance characteristics of the specimen with the entrapped air, and it minimizes the insulation effects due to radiation and surface
convection. An advantage of this instrument is that reproducible results may be obtained with a like instrument in other laboratories.

The constant temperature method was used by Marsh (29, p. T255). A pipe or other device was wrapped with the fabric to be tested and a constant temperature was maintained by controlling the source of heat. The amount of energy required to maintain the device at the fixed temperature was determined. A comparison of the results from one study to another is possible only when the same method is used.

A third method, the cooling method, measures the time required for a heated device to cool a given number of degrees. The results apply only to the apparatus used. The thermal insulating value is given as the ratio of time of cooling when unclad divided by the time of cooling when clad. This ratio is called the "comfort zone" by Black and Matthew (6, p. 203).

The use of these three methods of measuring thermal insulation value has shown the existence of several factors that are concerned with the warmth of fabrics. In his review of the literature Morris (33, p. T450) lists the factors that contribute to the thermal properties of textiles as follows:

1. The thermal conductivity of the fiber substance and of the air contained within the fabric.
2. The specific heat of the fiber substance.
3. The thickness of the fabric.
4. The bulk density of the fabric which should include consideration of the number, the size and the distribution of the air spaces.
5. The surface of the fabrics as affected by the type of fiber used, the construction of the fabric and the finishing treatments used.
6. The area of contact between the fabric and other surfaces.
9. Heat loss by convection from the skin through the fabric and from the fabric surface.
11. The heat gain due to water absorption by the fabric.
12. External atmospheric conditions such as the temperature, the relative humidity and air movement.

However, the properties of textile fabrics that are often discussed in relation to heat transmission are structure, thickness, density, porosity, compressability, and weight.

The structure refers to the variations that may occur in the fiber content, yarn and weave. Fiber content is considered by Schwarz (49, p. 637) to be important in the warmth of fabric only as it affects the porosity and the permeability of the fabric. The fiber content is of no importance, according to Aelion (2, p. 135), when fabrics have equal porosity and thickness. The distance at which a garment is worn or held from the body, according to Black and Matthew (6, p. 270), appears to have more effect upon the insulation value of the fabric than does the fiber content, whether wet or dry, or whether the body is wet or dry.

The study of characteristics for warmth in underwear
fabrics by Cassie (12, p. P444) shows that as the fiber surface is increased more air is entrapped and held, thus slowing the air movement. He points out that the accessibility of the fiber surface could be a contributing factor in determining the warmth of different fibers. If wool fabric has tightly twisted yarns and is tightly woven, its thermal conductivity will increase to eight times that of air; the thermal conductivity of fabrics that are made of plant fibers will increase to twenty times that of air. As a result of his study of rayon and wool blended fabrics, Cook (17, p. 114) stated that thermal transmission does not depend upon the fiber content but rather upon the construction and thickness of the fabric.

Freedman (20, p. 21) studied many factors that influence the thermal transmission of blanket fabrics. He investigated fiber content, fineness, staple length, structure, resilience, yarn construction, yarn number, twist and ply. He also considered the fabric construction, weave, yarn count, thickness, and the treatments that were given the fabrics at various stages of the processing. He concluded that increases in thermal insulation were due to fine wool fibers, high thread counts, and twill and crepe weaves as opposed to the plain weave, successive nappings, and increased permeability in slowly moving air. He also found that
an increase in humidity decreases the warmth of wool blankets.

Marsh (29, p. T271) found that blankets made of high quality wool have a higher insulation value than those of a lower quality.

In his discussion of thermal properties, Meredith (31, p. P532) states that the thermal resistance of a normal fabric is in direct proportion to the thickness of the fabric plus a known constant, which depends on the thermal resistance of the ambient air. He advocates dispensing with the direct measurement of thermal conductivity and replacing it with the simple measurement of fabric thickness. He found that fabrics of minimum weight that gave good insulation were made of fibers that had high bulking power. This in turn gave the thickness and high resilience which are necessary to maintain the thickness which is needed for warmth. Spilker's (52, p. 72) analysis of variance on wool and Orlon acrylic blankets did not show a direct relationship between thermal conductivity and fiber content. The two 100 percent Orlon acrylic blankets were the best insulators before laundering; however, they did not perform alike. This was attributed to the variation in denier of fibers and to the variation in yarn geometry. The thermal conductivity values, when adjusted for thickness using the analysis of covariance, resulted in Osborn's (58, p. 44) suggestion that if blends of fibers could be made to retain their thickness after laundering, they would
be equal, if not superior in heat retention to the 100 percent fiber blankets. Morris (33, p. T455) reports that "there is little difference between the specific heats of the different fibers with the exception of nylon which is higher than the others." He concludes, after reviewing the experimental work which had been done up to 1950, that good thermal insulation is obtained with thick fabrics irrespective of the fiber content.

Baxter and Cassie (5, p. T51) found that the weight of a fabric has little direct influence upon its thermal insulation value. Aelion (2, p. 138) states that "it can be argued that as the weight of a fabric is increased, while keeping it at the same thickness, the insulation capacity of the fabric will decrease." An increase in weight decreases the proportion of air to the fiber, thus introducing a larger proportion of the fiber which is the better conductor of the two. By increasing the thickness sufficiently a balance of air and fiber can be attained. Marsh (29, p. T252) found that washing lowered the thermal resistance, while renapping or brushing restored the thermal insulation to its former value. Shrinkage increased the thermal resistance by increasing the thickness of the blanket.

The insulative value was not always in direct proportion to thickness when different cleansing methods were used by Fahnestock and Stout (18, p. 188). Since the blankets varied in thickness, the
insulative quality was compared for a unit of thickness, and the results showed Acrilan to be the best insulator, followed in turn by wool and Orlon. Speakman and Chamberlain (51, p. T53) state that the total heat loss of a fabric is influenced by the density, the thickness, and the nature of the constituent fiber. The weave used in the fabric affects the warmth only if it alters the thickness or density (51, p. T42). Aelion (2, p. 135) reports that fabrics having the same thickness may have different densities, and thus there would be a difference in their insulation values. The study by Gilmore and Hess (22, p. 254) showed that "the heaviest and most expensive all-wool blanket would be slightly less protective than a paper blanket, if it was of the same thickness."

Schiefer et al. stated that generally "the thermal transmission of a blanket varies inversely with both thickness and compressibility." Hence, if thickness increases while compressibility decreases, the changes tend to annul each other in their effect on thermal transmission. There also appeared to be no correlation between blanket properties and fibers except for compressional resilience (45, p. 273). The means of the thickness determinations and the thermal conductivity values after the four laundry intervals indicate a significant difference, according to Osborn (38, p. 30). The regression of laundering treatments on the thermal conductivity was
quadratic and cubic with no evident linear regression (38, p. 33). The data indicates that wool blankets will continue to gain in thickness after ten launderings as a result of shrinkage; conversely there is a continuing loss in the thickness of the all-Orlon and all-Acrilan blankets after ten launderings.

The high association that exists between the thickness values and their corresponding thermal values was noted by Winston and Backer (60, p. 66). They stated that "thickness values should suffice for the present in predicting fabric performance on the laboratory equipment designed to evaluate thermal transmission of textiles under still-air conditions, where the fabric under test has not been subjected to dye or other treatment which would alter its normal radiation characteristics." Winston and Backer suggest that the development of synthetic fibers and fabric constructions, designed for service under special conditions may relegate thickness as the chief criterion of thermal characteristics to a position of less prominence. There is a direct relationship between thickness and warmth according to Mosedale (35, p. 97) and Aelion and Brown (3, p. 12). Thickness was also considered to be the most important factor in warmth by Black and Matthew (6, p. T210), Rees (42, p. T160), and Morris (33, p. T459).

The relationship of warmth to the porosity and to the
permeability of a fabric has been studied. The evidence that the capacity of a fabric to retain heat is related to its ability to entrap and hold air is supported by Cassie (13, p. P155), Winston and Backer (60, p. 62), Cassie (12, p. 447), and Bogaty, Hollies, and Harris (9, p. 445). Aelion (2, p. 135) states that there is not a relationship between heat loss and permeability in non-moving air. This type of air condition is encountered in such textile applications as blankets, underwear, and house clothes.

Freedman (20, p. 588) found that there was not a significant difference in the air permeability of blankets woven of either the lock, twill, or crepe weaves even though the blankets had similar fiber content and yarn construction. However, blankets woven with the plain weave had less air permeability. An article in Textile World comparing the percentage of thermal insulation that remained after six nappings of those blankets which were constructed of the lock, twill, crepe, and plain weaves, states that the twill and crepe weave provided the most warmth, the lock weave ranked next, and the plain weave provided the least warmth (28, p. 81). Air permeability varies inversely with the closeness of the weave. Regardless of the type of weave used, an increase in yarn count will result in a decrease in permeability, reports Freedman (20, p. 588).
Rogers, Hays and Hardy (43, p. 322) investigated wool blankets and their findings indicate that laundering significantly reduces the air permeability values, but that there is not a significant difference in the amount of heat that is transmitted. Skinkle (50, p. 109) points out that the comfort of body coverings is dependent upon an allowance for the evaporation of moisture from the body and that fabrics that have a certain amount of permeability will allow for such evaporation. The investigation of the physical properties of fabrics in relation to clothing by Black and Matthew (6, p. 212) showed that "wind exerts its greatest destructive effect upon the insulating value of the material at speeds from air up to about two feet per second, which corresponds to what is properly known as a draft. At speeds above two feet per second the rate of decay of insulating value is much less rapid."

A high negative coefficient of correlation between thickness and thermal conductivity values in Osborn's (38, p. 55) findings was interpreted as an affirmation of the inverse relationship between thickness and thermal conductivity. It was also noted by Osborn that the density of the fabric was responsible for a portion of the variation in the thermal conductivity of wool blankets after five and ten laundering treatments, but that there is less variation in the thermal conductance due to density of those blankets which are made of all-Orlon, all-Acrilan, rayon-Orlon, rayon-Acrilan,
or rayon-Nylon. The coefficient of correlation for density and thermal conductivity reveals that density has much less influence upon the thermal conductivity values than does thickness. Other investigators who have established that there is not a correlation between warmth and weight include Baxter and Cassie (5, p. T51), Marsh (29, p. T270), and Aelion and Brown (3, p. 12). Mosedale's tests revealed that air porosity is not a positive criterion of the heat insulation properties of a fabric (35, p. 186). However, air porosity may serve as an indicator as was illustrated in Mosedale's investigation in which he found that many blankets decreased progressively in their heat retaining ability after a series of launderings, and at the same time their resistance to the penetration of air increased markedly.

Another aspect of warmth to be considered is the property of compressional resiliency. The American Society for Testing Materials defines resilience as "that property of a material by virtue of which it is able to do work against restraining forces during return from a deformed state" (55, p. 30). They define compressibility as "the ease of squeezing" (55, p. 180). The compressibility of a blanket has been described by Schiefer (45, p. 262) as a measure of its loftiness. "A blanket having a low compressibility," he states, "is one which is greatly felled, little napped, and stiff or
boardy, and one having a high compressibility is lofty, soft, highly napped, and flexible. Schiefer defines compressibility of a fabric as "the ratio of the rate of decrease in thickness at a pressure of one pound per square inch to the standard thickness." It was reported in Modern Textiles that the Acrilan Mark III fiber was specifically designed in order to give more loft to blankets (1, p. 56). It has been determined that wool fiber does have enough resiliency to retain its dead air spaces, according to investigations by Cook (17, p. 114), Schiefer, et al. (45, p. 273), Schiefer (46, p. 24), and Mosedale (35, p. 186).

In their study of wool blankets Rogers, Hays, and Hardy (43, p. 321) found that as the matting of the fibers occurred with laundering, the compressibility decreased. They expressed compressibility as a percentage and calculated it as the ratio of the decrease in thickness at two pounds per square inch to the standard thickness at one-half ounce per square inch. Schiefer, et al. (45, p. 272) discovered that the compressional resilience of fibers decreased if they were damaged in use or in laundering. Compressional resiliency will increase if felting occurs with use or as a result of laundering. It has been suggested by Schiefer that there is less motion of the fibers in relationship to each other when a compressive load is applied. With less motion, less energy is required
for compression and in proportion the compressional resiliency increases. Coleman (16, p. 65) compared the average percentage of compressional resiliency after 20 launderings with the performance of the control fabric. Her results indicated that the compressional resiliency of the two fabrics did not vary more than six percent. This indicates that laundering did not have a major effect upon the compressional resiliency of the blankets.

The relationship of weight to warmth has also been examined. Marsh (29, p. T270) plotted the thermal insulation value against weight per unit area and determined that there is not a direct relationship between weight and thermal insulation. He suggests that there may have been a slight increase in the thermal insulating value as the weight increased. No definite relationship appears to exist between thermal insulating value and density in fabrics having the same weight or thickness, but there is a marked tendency for the less dense fabrics to show a higher thermal insulating value than the more dense fabrics. Coleman (16, p. 48) suggests that the weight per square yard of a blanket is a guide to its quality and thickness if the blanket has a 100 percent content of a specific fiber. Hess and Saville (27, p. 1058) recommend that a blanket measuring 72 by 84 inches must weigh 3.5 pounds in order to be warm and durable or both.
Among the many investigators who concur that the fiber is important only as it creates and maintains dead air spaces are Morris (34, p. 34), Schwarz (49, p. 637), Pierce and Rees (40, p. T184), and Marsh (29, p. T271). Morris (33, p. T464) states that "when two fabrics are of equal thickness, the fabric with the lower density has the greater thermal insulation. The type of fiber is of little consequence and a fabric of a given thermal insulation value can be produced from any fiber material provided it is sufficiently thick and suitably woven."

Much work has been done on the warmth of wool and there have been experimental studies with acrylic blankets that include the investigation of warmth. Coleman (15) studied one Orlon acrylic and three wool blankets with zero, one, five, ten, fifteen and twenty launderings. Fahnestock and Stout (18) used one brand of each blanket of the fibers Acrilan, Orlon, and wool with determinations after zero, one, two, three, four, and five cleansing processes. A comparison of an all-Orlon blanket with blends of rayon-Nylon and rayon-Orlon was made by Spilker (52). Osborn's (38) sampling included one wool, one Orlon, and one Acrilan blanket with zero, one, five, and ten laundering intervals. These authors have found it difficult to make any conclusive statements due to an insufficient depth in sampling.
The effect of maintenance upon the physical properties of wool and acrylic blankets was studied by Dr. Florence E. Petzel and co-workers (39) of the Oregon Agricultural Experiment Station at Oregon State University in Corvallis, Oregon. The interrelationship of the factors concerned with the thermal insulating capacity of Acrilan, Orlon, and wool blankets, as related to the maintenance procedures used, was a planned part of that study.

In the pilot study by Buckwalter (11) the physical properties that are related to the serviceability of wool and acrylic blankets were measured. These properties included yarn and weave structure, dimensional stability, yarn count, weight, thickness, breaking strength, resistance to abrasion, and the appearance of the blanket before laundering and after one, five, and ten launderings by a soaking method. Comparisons were made on the fiber content, price, air dry weight, yarn structure, and weave of four Acrilan acrylic, four Orlon acrylic, and four wool blankets. Portions of the blankets were laundered zero, one, five, ten, and twenty times in an agitator-type automatic washing machine with a washing method that consisted of soaking periods combined with small amounts of agitation. Before laundering and after each laundering period measurements were taken of the dimensional change, yarn count, thickness, weight, breaking strength, and resistance to abrasion.
The results of the pilot study indicated that there were changes in the properties of abrasion resistance, weight, breaking strength, dimensional stability, and thickness. These changes served as the basis for the formal study.

The pilot study showed that a majority of the blankets increased in their breaking strength after laundering. The increase in strength in the wool blankets may have resulted from the shrinkage; in the acrylic blankets this may have been caused by the matting of the fibers. Upon finding that wool and acrylic blankets were stronger after laundering than before, it was hypothesized that a factor in this change might be the matting of the nap on the surface of the blankets. The problem of determining whether this hypothesis was correct was investigated by Christensen (14). A study was made to determine the effects of denapping upon the breaking strength, thickness, and yarn count of the blankets which had been laundered ten times. It was concluded that some factor besides matting of the nap was associated with the increase in breaking strength per yarn after laundering.

The laundering caused the acrylic blankets' fibers to cluster, known as pilling, to mat and to develop a shaggy nap, while the nap of the wool blankets was somewhat felted and matted. Vincent contributed to the formal study by investigating the resistance of wool
and acrylic blankets to abrasion (56). The results of the pilot study by Buckwalter (11) showed that there was a higher mean percentage loss of weight by the wool blankets than by the acrylic blankets during abrasion. The study by Vincent was limited to the abrasion of the blanket by means of the Acceleror. The effects of abrasion were evaluated by changes in weight, thickness, and visual appearance with zero, one, five, and ten launderings. Acrylic blankets usually gained in thickness as a result of abrasion, possibly because of surface changes, while all of the acrylic blankets except one Acrilan acrylic and one Orlon acrylic decreased in weight. The acrylic blankets became very shaggy with abrasion. The wool blankets lost both in thickness and in weight because the nap was worn off by abrasion. The fibers of the wool blankets tended to pill on the surface and the pills broke off during abrasion. It was concluded by Vincent that further investigation of the other characteristics of the blankets of each fiber needed to be evaluated before the results of the abrasion resistance could be interpreted with confidence.

Shrinkage was a major change that occurred as a result of laundering. Shrinkage occurred in the wool blankets after each laundering; the shrinkage after 20 launderings was 17.5 percent as compared to 1.94 percent for the Acrilan acrylic and 1.04
percent for the Orlon acrylic. At the same time, the wool blankets increased in thickness after one laundering, but they decreased in thickness after five and ten launderings. The Acrilan acrylic blankets lost thickness progressively with increased laundering while the Orlon acrylic blankets behaved erratically by gaining and losing alternately, but with an overall loss.

The 100 percent wool, 100 percent Acrilan acrylic, and 100 percent Orlon acrylic blankets purchased in 1957-1958 were used in this investigation. This study to determine the effects of maintenance on the thermal insulation values of these selected blankets is the concluding work of the formal study initiated by Dr. Petzel (39).
METHODS AND PROCEDURES

The warmth samples that were used in this study were those that had been selected, laundered, and sampled for a previous study, "The Effects of Maintenance on Wool and Acrylic Blankets," by Dr. Florence E. Petzel and co-workers (39). Twelve blanket brands from nationally known manufacturers were selected for this previous study and three replicate blankets of each brand were purchased. Thirty-six blankets were sampled: 12 were Orlon acrylic, 12 were Acrilan acrylic, and 12 were wool blankets. The selection of the individual blankets was determined by their similarity of yarn structure, weave, and thickness.

The yarns in all of the blankets were of single ply construction. In all of the wool blankets the average warp yarn count was 26.7 yarns per inch and the average filling yarn count was 26.4 yarns per inch. This was also true of Acrilan acrylic blanket number 1 and Orlon acrylic blanket number 6. The remaining Acrilan acrylic and Orlon acrylic blankets had an average warp yarn count of 37.2 yarns per inch and an average filling yarn count of 33 yarns per inch. A semi-double weave was used for the three Orlon acrylic blankets numbered 5, 7, and 8; the twill weave, or a variation of the twill, was used in the construction of the nine remaining blankets.
Numbers were used to designate the blankets' brands. Numbers 1 through 4 were assigned to the Acrilan acrylic blankets, the numbers 5 through 8 indicated the Orlon acrylic blankets, and 9 through 12 identified the wool blanket. The blanket replicates from each manufacturer were lettered A, B, C, or D for ease in recording the data.

Each blanket was divided into four sections by cutting it approximately through the center lengthwise and crosswise. Each section was assigned to zero, one, five, and ten launderings on a random basis. A laundry pen was used to code a cotton twill tape which was stitched to each blanket quarter identifying the fiber content, the blanket replicate from which the section was cut and the number of times the section would be laundered. Four sections were reassembled into a single unit using a section from each of the four brands of the same fiber composition with a code number for the specific number of launderings.

Each reconstructed unit was laundered in a Norge automatic agitator-type washing machine. Nine gallons of water, an amount that measured 8.25 inches in depth, were used for washing and rinsing in the machine. The temperature of the water was 100°F ± 4°F. Forty-one grams of Dreft detergent were added and were dissolved by allowing the machine to agitate for one minute before the blanket was put into the machine. The blanket was soaked for
12 minutes. The water level was measured with a ruler at the end of this first soaking period to find the exact amount of water needed to maintain the water level throughout the washing and the rinsing processes. After the initial 12 minute soaking period the blanket was turned by hand and soaked for an additional eight minutes, making a total soaking time of 20 minutes. The water was extracted for two minutes by manually setting the control dial on the spin cycle of the machine. The blanket was left in the washer while the rinse water was added.

The washer was again filled with water at $100^\circ$ F to the measured level of the first soaking period. It was soaked for three minutes, turned by hand, and soaked for an additional two minutes. The water was extracted for two minutes on the spin cycle after which the blanket was given a second rinsing by following the same procedure used in the first rinsing.

Immediately after the second rinsing and extraction of water the blanket was folded and three large heated terry towels were placed within its folds. The folded blanket and two other heated towels were then placed in the dryer and were partially dried for ten minutes at the temperature setting indicated for blankets. The towels were used in the dryer to prevent creases from forming, to restrain any abrasion that may have resulted from contact with the
metal cylinder of the dryer, and to aid in the drying process. After the partial drying period the blankets were removed from the dryer and were hung over two lines in a room having an average temperature of 85° F. A fan was used to circulate the air and the drying process was completed overnight.

Because the dimensions of each blanket changed during the laundering process, cutting-layout diagrams were planned for each blanket condition after it had been washed and dried the specified number of times. The cutting diagram included test specimens for determining the thickness, weight, breaking strength, abrasion resistance, and warmth. Fifteen warmth test specimens measuring five inches square were cut from the zero or control section, and 15 were cut from each of the one, five, and ten laundering sections. Twenty test specimens were cut from each of the three replicates of a brand. A total of 720 specimens were coded and prepared for storage. Thread loops were fastened at two adjacent corners of each specimen and were suspended on two parallel wire lines which were spaced close enough to prevent the sample from stretching. The samples were completely wrapped with paper for protection.

In the preparation for this study, the specimens were removed from storage and were conditioned in a controlled atmosphere where the temperature was maintained at 72° F ± 2° F with
a relative humidity of 65 percent + 2 percent. The specimens for the determinations of warmth were conditioned in this room for 24 hours before any laboratory measurements were made and they were kept in this room at all times during the study. The laboratory measurements on each specimen included a thickness reading with the Compressometer and a thermal insulation determination on a modified Cenco-Fitch heat transfer apparatus.

The Compressometer, which had a presser foot three inches in diameter, was used to determine the thickness of each specimen. This thickness was measured to the nearest 0.001 inch at a pressure of 0.01 pounds per square inch. This pressure has been considered sufficient to insure contact between both plates of the test instrument and the fabric without causing appreciable deformation of the fluffy blanket material.

In order to prepare the instrument for use, a spirit level was centered on the base and the instrument was leveled. The calibration of the dials was checked with a Jo block. The base of the instrument was kept clean at all times by brushing it with a camel’s hair brush.

A specimen was centered without tension upon the base under the presser foot. The presser foot was lowered gradually without impact onto the fabric by turning the wheel counterclockwise. A
timer was started when the pressure was 0.01 pounds per square inch as indicated on the upper dial by the number 4. After ten seconds the lower dial was read to the nearest 0.001 inch. The readings were recorded as whole numbers on the data sheets.

The Cenco-Fitch instrument used for the warmth determinations consists of two parts, the heat source and the receiver. The upper part or heat source is a cylindrical vessel which has a three inch copper block centered in the bottom of the vessel. The vessel was filled with mineral oil which was heated to a constant temperature of 100°C ± 1°C. The oil was heated with a knife-type immersion heater which was suspended from a clamp on a ring stand. A thermometer was also suspended close to the heater in the center of the oil. The lower part or receiver consists of a one and three-quarter inch copper block which is surrounded by insulating materials. A thermocouple pair with junctions embedded in the copper blocks of the two parts acts to produce a weak electric current when the two members of the pair differ in temperature. The strength of the current is directly proportional to the difference in temperature.

The copper blocks of the heat source and heat receiver were connected to a sensitive microammeter in series with a slide rheostat. As heat from the source was transferred through the fabric to the receiver, the difference in temperature between the source
and receiver became less and the reading of the microammeter decreased proportionately. The microammeter reading is a measure of the temperature difference between the two blocks. The difference was sufficient enough to throw the deflection off scale and it was necessary to shunt the resistance by a reduction factor of 200 in order to reduce the temperature difference and to attain a full scale deflection. A constant voltage transformer was necessary to keep the oil at a constant temperature in the vessel and to maintain a fluctuation of no more than $\pm 1^\circ C$ during the testing.

The heat transfer apparatus was modified to enable the operator to raise and lower the heat source and to accurately control the distance between the two parallel surfaces. A dial micrometer which records to 0.001 of an inch was set to equal the premeasured thickness of the specimen being tested. The vessel and receiver were mounted on a base equipped with leveling screws and the base for the apparatus was kept level at all times.

The levelness of the copper blocks in each of the receivers was checked with a spirit level before the thermal measurements were made. A Jo block was used to check the accuracy of the micrometer dial reading on each of the receivers.

The level of the mineral oil in the vessel was maintained one inch from the top of the vessel when the oil was at room temperature. The rheostat was adjusted to keep the oil at constant
temperature and was never adjusted during a test.

Three receivers were used to allow for continuous testing.
The specimen was placed on a receiver which was at the temperature of the control room at the beginning of each determination.
The receiver and the specimen were inserted below the heat source, the wires connected to the terminals on the receiver, and the vessel was lowered until the distance between the copper blocks equaled the pre-measured thickness of the blanket specimen. A piece of heavily felted woolen fabric was fitted around the lower part of the instrument to reduce lateral heat loss.

When the microammeter read exactly 143, a timer was started and microampere readings were recorded. Each test period lasted for 21 minutes with seven readings at three minute intervals. The needle of the microammeter face was always aligned with its mirrored reflection to avoid parallax error. The method was adopted from Morris (34).

After each test the receiver was cooled for ten minutes by placing a 150 milliliter breaker of ice on a paper towel on top of the metal portion of the receiver. After the ten minute cooling period, the beaker and the paper towel were removed and the receiver was allowed to cool for one hour before it was reused. To remove the moisture which collected on the composition surface around the eye of the receiver, as a result of the
cooling method, each receiver was placed in a drying oven at 110° C for a total of 22 hours out of every 48 hours.

The instrument was not turned off during the testing series. The shunt was set on zero when it was not in use and a fabric specimen was left on top of a receiver in its normal position beneath the heat source. The felted woolen wrapping was also kept in place. This enabled the investigator to begin testing after running one trial test to check on the temperature and to allow the instrument to regulate itself. Mineral oil was added when necessary in order to keep the element in the knife heater covered and the oil was replaced when it became discolored so that the knife heater was not visible.
DATA AND DISCUSSION

The analysis of variance was used to evaluate the data obtained from the testing for thickness and thermal conductivity. The t test at the five percent level was used to evaluate the effects of laundering upon the thermal conductivity of the blankets. All other tests for significance that were analyzed in the data are at the one percent level. The analysis of covariance was considered impractical for use in evaluation of the data because there was no evident linear regression when the thermal conductivity values were plotted against the thickness.

Specific information regarding the fiber content, size, price, yarn count, weave and weight of each blanket is given in Table I, page 36. Each blanket is identified throughout the discussion by its previously designated number, and a letter is used to depict the fiber content. The Acrilan acrylic blankets are identified by the letter A; the Orlon acrylic blankets by the letter O and the wool blankets by the letter W.

Effects of Laundering Upon the Dimensional Change

Shrinkage caused a major change in the dimensions of the wool blankets. There was much less shrinkage in the Acrilan acrylic and the Orlon acrylic blankets. The chart in Figure I, page 37 shows
### Table I. Fiber Content, Size, Price, Yarn Count, Weave and Weight of Blankets

<table>
<thead>
<tr>
<th>Fiber Content and Blanket Number</th>
<th>Width and Length on Label (inches)</th>
<th>Price Retail (dollars)</th>
<th>Yarn Count* Per Inch</th>
<th>Weave</th>
<th>Air-dry weight ** of blankets lbs. oz. oz/sq/yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrilan 1</td>
<td>72 x 90</td>
<td>$14.95</td>
<td>26.2 20.1</td>
<td>2 x 2 twill</td>
<td>2 9.0 7.859</td>
</tr>
<tr>
<td>Acrilan 2</td>
<td>72 x 90</td>
<td>12.95</td>
<td>29.9 31.0</td>
<td>twill variation</td>
<td>2 13.6 8.731</td>
</tr>
<tr>
<td>Acrilan 3</td>
<td>72 x 90</td>
<td>13.95</td>
<td>35.8 27.0</td>
<td>twill variation</td>
<td>3 2.2 10.534</td>
</tr>
<tr>
<td>Acrilan 4</td>
<td>72 x 90</td>
<td>15.95</td>
<td>36.2 36.2</td>
<td>twill variation</td>
<td>3 2.4 10.512</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>32.0 28.7#</td>
<td></td>
<td>9.409#</td>
</tr>
<tr>
<td>Orlon 5</td>
<td>80 x 90</td>
<td>15.95</td>
<td>35.8 37.5</td>
<td>semi-double</td>
<td>3 11.5 10.985</td>
</tr>
<tr>
<td>Orlon 6</td>
<td>72 x 90</td>
<td>9.95</td>
<td>23.5 23.5</td>
<td>2 x 2 twill</td>
<td>3 2.1 9.905</td>
</tr>
<tr>
<td>Orlon 7</td>
<td>72 x 90</td>
<td>16.95</td>
<td>41.5 36.0</td>
<td>semi-double</td>
<td>3 4.5 10.850</td>
</tr>
<tr>
<td>Orlon 8</td>
<td>72 x 90</td>
<td>12.95</td>
<td>44.2 29.8</td>
<td>semi-double</td>
<td>3 6.1 10.317</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36.2 31.7#</td>
<td></td>
<td>10.522#</td>
</tr>
<tr>
<td>Wool 9</td>
<td>72 x 90</td>
<td>12.25</td>
<td>27.3 18.1</td>
<td>twill</td>
<td>3 8.3 11.034</td>
</tr>
<tr>
<td>Wool 10</td>
<td>80 x 90</td>
<td>19.95</td>
<td>23.9 27.6</td>
<td>twill</td>
<td>3 5.3 11.226</td>
</tr>
<tr>
<td>Wool 11</td>
<td>72 x 90</td>
<td>17.00</td>
<td>24.4 17.5</td>
<td>2 x 2 twill</td>
<td>4 2.8 13.093</td>
</tr>
<tr>
<td>Wool 12</td>
<td>72 x 90</td>
<td>25.00</td>
<td>31.2 42.2</td>
<td>twill variation</td>
<td>4 8.5 14.718</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26.7 26.4#</td>
<td></td>
<td>12.518#</td>
</tr>
</tbody>
</table>

* Yarn count - means of twelve determinations
** Weight - means of fifteen determinations
# Mean of the means of yarn count and weight
Figure I. Percentage Warpwise and Fillingwise Dimensional Change After Laundering According to Fiber Content
the dimensional changes of the blankets after zero, five, and ten laundering periods. The wool blankets shrank in both the warp and filling directions, whereas, the warp yarns of the Orlon acrylic blankets stretched while the filling yarns shrank. The performance of these blankets suggests that the wool blankets did not have a shrink-resistant finish and that careful laundering by mild methods may result in some dimensional change in both wool and acrylic blankets.

Investigators have found that wool blankets usually shrink more in the warp direction than in the filling direction; they have also noted that wool blankets tend to shrink the most in the first laundering period and that they shrink progressively with successive launderings (22; 24; 43; 45). The chart in Figure II, page 39 illustrates these findings. There appears to be more deviation in the behavior of the filling yarns than in the warp yarns of the wool blankets. This deviation is especially noticeable in the wool blanket W9. The filling yarns stretched after one and five launderings and shrank after ten launderings. The wool blanket W10 performed opposite to W9 by first shrinking rapidly after one and five launderings, and then stretching after ten launderings.

The wool blankets tended to weigh more than the acrylic blankets after each laundering interval. A graphic comparison of the weight change is shown in Figure III, page 40. The wool
Figure II. Percentage Warpwise and Fillingwise Dimensional Change in Wool Blankets After Laundering.
Figure III. Mean Weight Change After Laundering
blankets were the heaviest before laundering and were the heaviest after laundering. They were followed in turn by the Orlon acrylic blankets and the Acrilan acrylic blankets.

Effects of Laundering Upon the Thickness

Table II, page 42 shows the means of the thicknesses of each blanket before and after laundering. The thickness of the wool blankets was higher in every test condition than the thickness of either the Orlon or Acrilan acrylic blankets. The Orlon acrylic blankets were not as thick as the wool blankets; the Acrilan acrylic blankets were thinner than either the wool or Orlon acrylic blankets in all the test conditions. Table II also shows an increase in the thickness of the Orlon acrylic and wool blankets after one laundering; it shows the Acrilan acrylic blankets decreased in thickness after one laundering. The change in thickness after one laundering was followed by a decrease in thickness after five launderings regardless of the fiber content. A further decrease in thickness was noted in the Acrilan acrylic and Orlon Acrylic blankets after ten launderings, whereas the wool blankets showed an increase in thickness.

The significant relationships found in the changes in thickness shown in Table II, page 42 involve both decreases and increases in thickness. The Acrilan acrylic blankets and the wool blankets had a significant decrease in thickness from the zero laundering interval
Table II. Mean Thickness in Inches

<table>
<thead>
<tr>
<th>Fiber Content and Blanket Number</th>
<th>Number of Launderings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Acrilan</td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>.200</td>
</tr>
<tr>
<td>A2</td>
<td>.220</td>
</tr>
<tr>
<td>A3</td>
<td>.264</td>
</tr>
<tr>
<td>A4</td>
<td>.265</td>
</tr>
<tr>
<td>Mean</td>
<td>.237</td>
</tr>
<tr>
<td>Orlon</td>
<td></td>
</tr>
<tr>
<td>O5</td>
<td>.249</td>
</tr>
<tr>
<td>O6</td>
<td>.257</td>
</tr>
<tr>
<td>O7</td>
<td>.271</td>
</tr>
<tr>
<td>O8</td>
<td>.314</td>
</tr>
<tr>
<td>Mean</td>
<td>.273</td>
</tr>
<tr>
<td>Wool</td>
<td></td>
</tr>
<tr>
<td>W9</td>
<td>.271</td>
</tr>
<tr>
<td>W10</td>
<td>.278</td>
</tr>
<tr>
<td>W11</td>
<td>.295</td>
</tr>
<tr>
<td>W12</td>
<td>.304</td>
</tr>
<tr>
<td>Mean</td>
<td>.287</td>
</tr>
</tbody>
</table>

* Mean of 15 determinations
to the fifth laundering interval and also to the tenth laundering interval. The Orlon acrylic blankets had a significant increase in thickness from the zero laundering interval to the fifth laundering interval. All other relationships in the table were not significantly different.

Laundering may change the initial thickness of a blanket by causing it to stretch and/or shrink. The data indicates that the variation in thickness among blankets of the same fiber content was sometimes greater than the variation between the blankets composed of the three fiber groups. Table II, page 42 shows that the only Acrilan acrylic blankets that had significant changes in thickness were A1 and A2. The most noticeable change in blanket A1 was an increase in thickness after five launderings. According to the findings by Petzel (39) regarding the dimensional stability of each blanket, the highest amount of shrinkage for blanket A1 occurred after five launderings. The Acrilan acrylic blanket A2 progressively decreased in thickness with each laundry interval. This particular blanket decreased in weight after one and five launderings and shrank both in the warp and filling directions. The loss in weight and thickness and the shrinkage in both the warp and filling directions indicates that there was a loss of fiber during the laundering intervals.

The Acrilan acrylic blankets A3 and A4 and the Orlon
acrylic blankets 05 and 06 did not have significant changes in their thicknesses throughout the laundry intervals. There was little change in the dimensions and in the weight of these four blankets.

The Orlon acrylic blankets 07 and 08 had significant increases in thickness after one laundering. This may be attributed to the shrinkage that occurred in the filling yarns.

The wool blankets had many significant changes in thickness as a result of laundering. The blanket W9 showed a decrease in thickness following the first and fifth laundry intervals, and a subsequent increase in thickness after ten launderings. However, the blanket never regained its initial thickness. It can be noted that each laundry interval caused a change in thickness that was significantly different from the initial thickness. However, the increase in thickness from the fifth laundry interval to the tenth laundry interval was not statistically significant. The chart shown in Figure II, page 39 indicates that blanket W9 stretched in the filling direction from the first laundering past the fifth laundering. This dimensional change may have caused the decreases in thickness that were found during the first and fifth laundry intervals. The stretching of the filling yarns was not counterbalanced by the continuous shrinkage of the warp yarns. The chart also shows W9 began to shrink in the filling direction and continued to shrink in the warp direction between the fifth and tenth launderings intervals. The change in
the behavior of the filling yarns may have caused the increase in thickness between the fifth and tenth laundry intervals.

Wool blanket W10 showed a gradual decrease in thickness with each additional laundering interval. The decrease in thickness caused by one laundering was not statistically significant from the initial thickness; however, both the fifth and tenth laundering intervals caused significant decreases in thickness when compared to the original thickness. It is interesting to note in Figure II, page 39 that blanket W10 shrank in the warp direction continuously and that in the filling direction it first shrank and then stretched, with a resulting decrease in thickness. According to Petzel's (39, p. 374) findings, this blanket gained weight and lost thickness, which could be an indication of excessive felting or matting of the fibers.

The changes in thickness of blankets W11 and W12 were erratic under the laundering test conditions. Both blankets had an increase in thickness after one laundering. This was followed by a decrease in thickness after five launderings and an increase in thickness after ten launderings. The thickness of blanket W11 did not change significantly between the fifth and tenth laundering intervals. This suggests that the continuous shrinkage shown in Figure II, page 39 was responsible for the overall increase in the thickness of blanket W11. Blanket W12 was initially the thickest wool blanket in the test sampling. This blanket decreased in thickness
significantly after one laundering, but its thickness was not significantly influenced at either the fifth or tenth laundering intervals.

The shrinkage in wool due to laundering usually caused an increase in the thickness and density of the blanket. This change may be due to several factors. One factor is the strains which are applied to the fibers in processing. These strains may not be permanently set, and recovery may take place from them during use and laundering. Secondly, the fibers swell when they absorb moisture, either from the atmosphere or from the water used in laundering. The swelling of the yarns may cause a redistribution of the crimp. A third factor is felting where the scales of the fiber move closer to the root end of the hair under moist conditions.

The readings for thickness indicated that wool blankets tend to be thicker than the Orlon and Acrilan acrylic blankets after laundering. They may be thicker than their original thickness. The process of laundering usually decreased the thickness of a blanket because of the loss of some fibers, however, shrinkage sometimes counteracts this effect and restores or increases thickness. The retention of the original thickness, according to the results of the analysis of the thickness means, seemed to be more dependent upon the construction of the blanket than it was upon the fiber content.
The Effect of Laundering Upon the Thermal Conductivity Values

The multiple significant relationships that occurred in the means of the thickness values as a result of laundering were compounded when the means of the thermal conductivity values were analyzed. The result of the compounding of the significant relationships in thickness upon the means of the thermal conductivity values caused almost every relationship analyzed for thermal conductivity to be statistically significant. It was therefore felt that any analysis of the thermal conductivity means should be considered as an indication of quality in construction of the blankets. When the consumer selects a blanket, the warmth of that blanket cannot be predicted because the warmth is controlled by the thickness of the blanket and its ability to retain that thickness with laundering.

The conventional method devised by Brown (10, p. 74) was used for the calculation of the thermal conductivity values obtained with the Cenco-Fitch instrument. The average of the slope of the microammeter readings was plotted against the time elapsed at each reading. The means of the slopes of the resulting straight line was estimated by the method of least squares using the following equation:

\[ K = \frac{2.303 \ M \ s}{m \ A^2} \]
The specific values for the instrument used in this investigation are:

\[ M = 340 \text{ grams (mass of the receiver)} \]

\[ s = \text{specific heat of copper in calories per gram} = 0.0936 \text{ cal/grm.} \]

\[ A = \text{area of the copper block in square meters} = 15.52 \text{ sq. cm.} \]

All thermal conductivity values used in the analysis and discussion of data are in the form of $1000^\circ \text{C}$. and the units are calories per degree centigrade, per second, per 1000 centimeters squared.

The numerical values shown in Table III, page 49 represent the means for 60 thermal transmission determinations for each blanket and 15 thermal transmission determinations for a specific laundry interval. The figures in the table compare the amount of heat that is transmitted through each blanket brand for each laundry interval. A lesser amount of heat was transmitted when the reading of the mean value for thermal conductivity was numerically lower. Therefore, the thermal insulation capacity of a specific blanket was higher when the value for the thermal conductivity was a low number. Table III, page 49 presents the data showing the means of the thermal transmittance before the values were corrected to compensate for the variation in the thickness of the blankets in zero condition. When the means of the thermal conductivity values were adjusted for the variation in thickness there was not a significant difference in the amount of heat that was transmitted by either
Table III.  Mean Thermal Conductivity per .001 Inch Thickness of Blankets and Means According to Fiber Content

<table>
<thead>
<tr>
<th>Fiber Content and Blanket Number</th>
<th>Number of Launderings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Acrilan</td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>9.40</td>
</tr>
<tr>
<td>A2</td>
<td>8.58</td>
</tr>
<tr>
<td>A3</td>
<td>6.93</td>
</tr>
<tr>
<td>A4</td>
<td>6.86</td>
</tr>
<tr>
<td>Mean</td>
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<tr>
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<tr>
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an Acrilan acrylic, Orlon acrylic or wool blanket. This implies that warmth depends upon the thickness of a blanket and the retention of that thickness rather than upon the fiber content. This finding is in agreement with Morris (28) who stated in 1953 that "The type of fabric is of little consequence and a fabric of a given thermal insulation value can be produced from any fiber material provided it is sufficiently thick and suitably woven."

The analysis of the means for thermal conductivity of each laundering interval indicated that the warmth of the blankets was more dependent upon the construction than it was upon the fiber content. The only relationship in which there was not a significant effect upon the thermal conductivity as a result of laundering was the zero to one laundering interval for the Orlon acrylic blanket O6. Every other interaction of the means for thermal conductivity for all the blankets was significant. The degree of variation in the significant interactions between the means was calculated, this was then related to the effect of laundering upon the thickness of the blankets in the discussion that follows.

The Relationship of the Thickness and Thermal Conductivity Values

The chart in Figure IV, page 51 shows the corrected means for thermal conductivity per each 0.001 inch thickness at the various laundering intervals for each blanket. The effect of the variation
Figure IV. Mean Thermal Conductivity Per .001 Inch Thickness of Blankets
in the thickness caused by laundering upon the thermal conductivity was included in the chart. The effect of laundering on the thickness of the blankets is shown in Table IV, page 53.

A comparison of Figure IV, page 51 and Table IV, page 53 shows that the thickest blankets have the lowest thermal conductivity values and that they are the best insulators; the thinnest blankets have the largest thermal conductivity values and have the least insulation value. Figure IV and Table IV emphasize the importance of the retention of thickness for the maintenance of warmth. Blankets O8, W11, and W12 are the thickest blankets and they are the best insulators. The blankets which fall at the median in thickness and warmth retention are W9, W10, O5, O6, O7, A3, and A4. The thinnest blankets and the poorest insulators were blankets A1 and A2. There is however, no way to relate these findings to warmth in actual use of the blankets. Therefore blankets A1 and A2 might be adequate insulators during normal use.

Four blankets have comparable warmth characteristics at the zero laundering interval as shown by Figure IV, page 51. Warmth characteristics are considered comparable when the results of the warmth test are similar for a particular condition. Blankets O5 and W10 are similar, as are blankets A3 and A4, in the zero laundry interval. The thermal conductivity values of the remaining blankets in the zero interval are all significantly different from
<table>
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<td>.32</td>
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<td>.19</td>
<td></td>
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<td>A2</td>
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<tr>
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<td>.19</td>
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each other.

There is a significant difference in the thermal conductivity values of all the blankets after one laundering. After five launderings the thermal conductivity values in blanket O6 were comparable to the blankets W9 and W10. The remaining values for the other blankets in the fifth laundering interval were all significantly different from each other. In the tenth laundering interval the only blankets with similar thermal conductivity values were blankets A4 and W9. All other comparisons in the tenth laundering interval had thermal conductivity values which were significantly different.

A comparison of the thermal conductivity values in Figure IV, page 51 and the thickness measurements in Table IV page 53 reveals the following behavior. Generally an increase in thickness created an improvement in insulation value and a decrease in thickness caused a decrease in insulation value. Blankets A4, O5, O8 and W12 became thicker after one laundering and improved their insulation value. As a result of one laundering, blankets A2 and W9 became thinner and lost their original insulation values. Blankets A1, A3, and W10 did not change in thickness and improved in insulation value, whereas blanket O6 did not change in thickness and it lost some of its warmth after one laundering. Blankets O7 and W11 both gained in thickness but became slightly poorer insulators after one laundering.
Five launderings generally caused a loss of thickness and a loss of warmth for blankets A3, O5, O7, O8, and W10. The only blanket that increased in thickness and became warmer after five launderings was blanket A1. Five launderings made blankets A2, A4, W9, W11, and W12 thinner and improved their insulation values. Blanket O6 again had no change in thickness due to five launderings and it again had a decrease in insulation value.

Ten launderings caused blankets A1, A3, O8, and W10 to lose thickness and warmth. The only blankets that lost neither thickness nor warmth during the fifth to tenth laundering interval were blankets A2 and A4. Blanket W9 became thicker and gained warmth after ten launderings. Blankets O5 and O7 did not change in thickness after ten launderings but they became better insulators; blanket O6 did not change in thickness but it became a poorer insulator. Blanket W11 did not change in thickness or warmth from the fifth to the tenth laundering.

The gradual loss of thickness which caused a decrease in warmth may have been due to a loss of fibers, to stretching or both. The gradual loss of thickness and warmth was noted in blanket W10. The loss of thickness which was accompanied by an increase in thermal insulation value may have been the result of shrinkage when the fibers matted or felted. The matting or felting increases the compactness, giving a subsequent improvement in thermal insulation
value. The changes in the surface texture of the blankets may have created more air spaces and thus improved insulation for some of the blankets. It is also possible for a blanket to become so compact due to a reduction in the air spaces, that heat is rapidly conducted away from the body. This type of behavior may have been exhibited by blanket W10 which gained weight, lost thickness and gradually lost its ability to insulate.

The Orlon acrylic blanket O8 was the thickest blanket and the best insulator in zero condition and after one laundering. The Orlon acrylic blankets O5, O7, and O8 were woven with semi-double weaves. The Orlon acrylic blanket O6 had a twill weave. The semi-double weave, with its two sets of filling yarns and one set of warp yarns gave more thickness and more warmth. The blankets with the semi-double weaves shrunk more in the filling direction than they did in the warp direction. The increase in density through shrinkage of the Orlon acrylic blankets O5, O7, and O8 may be the reason for their higher insulation value as opposed to blanket O6 which appeared to gradually lose its insulation value and its thickness.

The insulation value of wool blankets W11 and W12 improved as they progressively shrunk during each of the laundering periods. It would seem that the thermal insulation value of a blanket is dependent upon its thickness and dimensional stability, which is
related to the quality of the construction used by the manufacturer.

In the application of the findings of this study to the selection of a blanket, there are some factors other than ease of care and dimensional stability which should be considered. These factors are cost, weight, thickness, weave, yarn count and warmth. A label which includes information the consumer could interpret regarding each of the factors stated above would aid the alert consumer in the selection of a blanket.

The consumer usually desires the best buy for the most reasonable price. The costs to be considered in the purchase of a blanket include not only the initial cost but the cost of maintenance. Both the acrylic and wool blankets can be washed successfully in the home, but the wool blanket will require much more care in handling to prevent shrinkage.

A blanket needs to weigh a minimum of three and one-half pounds in order to retain its thickness and warmth throughout use (27). A heavier blanket would be expected to give additional desired thickness and warmth.

When the initial price, maintenance costs, weight, thickness, and warmth for each of the blankets was considered the Orlon acrylic blanket O8 appeared to be a desirable choice for $12.98. It costs less than the Orlon acrylic blankets O5 and O7 and the wool blankets W11 and W12. These five blankets were the best
insulators and, if the final choice were dependent upon the cost, the
purchase of an Orlon acrylic blanket would appear to be desirable.
The Orlon acrylic blanket with a semi-double weave construction
weighing approximately three and one-half to four pounds should give
satisfactory service in return for half the price of the best woolen
blanket.

The acrylic blankets have an added advantage when compared
to wool because they are moth resistant. However, the low moisture
absorbency of the acrylic blankets may make their use objectionable
to some individuals. The body constantly loses both heat and mois-
ture and a comfortable blanket must allow for the gradual escape
of this heat and moisture. A wool blanket is absorbent and it gives
off heat as it allows the moisture to evaporate. The higher moisture
absorption capacity of the wool blankets would recommend their use
when the purchase cost and maintenance costs are not important
considerations.

Another consideration is the appearance of the blankets after
laundering as was reported by Petzel (39). The Acrilan acrylic
blankets were pilled and shaggy in appearance. The Orlon acrylic
blankets were pilled, matted and shaggy. The wool blankets were
felted and somewhat matted. The acrylic blankets and some of the
wool blankets tended to become more harsh in texture. This gives
the consumer a choice between a shaggy appearing acrylic blanket
as opposed to the pilled and felted wool blanket. The best guide for selection of a blanket is still a brand name with a good reputation and a business firm to whom you may return your purchase if the merchandise is not satisfactory.
SUMMARY AND RECOMMENDATIONS

The present study was undertaken to compare the warmth of four Acilan acrylic blankets, four Orlon acrylic blankets, and four wool blankets after zero, one, five and ten launderings. The blankets used in this investigation were those which had been previously selected by Petzel (39). These blankets had been laundered prior to this study using a procedure that Petzel (39) considered mild. The procedure consisted of soaking periods with small amounts of agitation. Cutting diagrams were developed for the laundered sections of the various blankets. The 720 warmth test specimens, each measuring five square inches, were cut, coded and stored with a protective covering previous to this study.

After preliminary work on the test method the warmth test specimens were transferred to a room with a controlled atmosphere where the temperature was maintained at 72°F ± 2°F. with a relative humidity of 65 percent ± 2 percent. Thickness and warmth determinations were then made to ascertain the effects of laundering upon the thermal conductivity value of the blankets. The thickness measurements were taken with the Compressometer at a pressure of 0.01 pounds per square inch. The warmth tests were made using a modified Cenco-Fitch instrument.

The findings of the research conducted by Petzel (39) which
had a bearing on the test specimen used in this study were examined for the behavior which they demonstrated. The warp and filling dimensional changes after laundering were discussed and related to the fiber content of the various blankets. It was found that the wool blankets shrank more in the warp direction than in the filling direction; they also tended to shrink the most in the first laundering period and they shrank progressively with successive launderings.

In the weight comparisons it was reported that the wool blanket weighed more than the acrylic blankets before laundering and after each additional laundering interval. The Orlon acrylic blankets were the next in weight and the Acrilan acrylic blankets weighed the least.

The effect of laundering upon the thickness of each blanket before and after laundering was measured. The results generally showed the wool blankets were thicker in every test condition followed in turn by the Orlon acrylic and Acrilan acrylic blankets. The blankets usually gained in thickness after one laundering followed by a gradual decrease with additional launderings. Laundering may change the initial thickness of a blanket by causing it to stretch and/or to shrink. The data indicated that the variations in thickness among blankets made of the same fiber content were sometimes greater than the variations among the blankets composed of the three fiber groups being tested.
A combined weight and thickness loss was considered an indication of a loss of fibers during laundering. A gain in weight and a loss in thickness was considered an indication of excessive felting or matting of the fibers. The process of laundering usually decreased the thickness of a blanket because of a loss of some fibers, however, shrinkage sometimes counteracted this effect and restored or increased the thickness. The retention of the original thickness seemed to be more dependent upon the construction of the blanket than it was upon the fiber content.

The many significant relationships that were found in the analysis of the data concerning the thickness values as a result of laundering caused almost every relationship analyzed for thermal conductivity to be statistically significant. Because of the compounding effect of the relationships, the analysis of the thermal conductivity was considered to be an indication of quality in the construction of the blankets. It was concluded that heat retention is controlled by the thickness of the blanket and its ability to retain its thickness after laundering rather than upon the fiber content. The thickest blankets in the research study of Gilmore and Hess (22, p. 256) were the warmest and both laundering and drycleaning increased the protective value of all their selected wool blankets. The comparison of part wool to all-wool blankets after laundering by Schiefer, Mizell, and Mosedale (47, p. 204) showed that shrinkage was the cause for
increases in thickness, breaking strength, and weight per square yard; and for decreases in compressibility, air permeability, and thermal transmission. A decrease in thermal transmission is interpreted to mean an increase in thermal insulation value.

The thicker blankets were the better insulators and the thinner blankets had less insulation value. A loss in thickness and an increase in thermal insulation value may be attributed to a matting or felting of the fibers. These changes could have increased the compactness and given a subsequent improvement in the insulation value. When a blanket becomes too compact there is a more rapid conduction of heat away from the body due to reduced air spaces. A compact or felted blanket usually gains excessive weight while it loses thickness and its ability to insulate. The thermal insulation value of the blankets seemed to be dependent upon their thickness and dimensional stability which resulted from the construction used by the manufacturer.

Better labeling by manufacturers would aid the informed consumer in the selection of a blanket. Cost, weight, thickness, weave, yarn count and warmth information need to be made understandable in terms of performance for the consumer.

The costs to be considered before purchasing a blanket include the initial cost, and the continuing cost of maintenance. The initial cost of the acrylics is generally lower and the maintenance costs
are less. A blanket needs to weigh a minimum of three and one-half pounds in order to retain its thickness and warmth throughout use. A heavier blanket would be expected to give additional desired thickness and warmth. The higher moisture absorption capacity of the wool blankets gives them an advantage. The consumer has a choice to make in blanket selection regarding the general appearance of the blankets after laundering. She can generally expect the acrylic blanket to become shaggy and pilled and the wool blanket to become pilled and somewhat matted.

Much work needs to be done in regard to warmth testing. The terminology used in interpreting test findings varied because an inexpensive, yet satisfactory test method has not been established or generally accepted. The Cenco-Fitch instrument creates a basis on which an additional comparison of quality in construction of blankets can be made. The warmth tests should not be isolated from findings on dimensional stability, yarn count, weave, weight and thickness.

The Cenco-Fitch instrument measures the heat transmitted by conduction and therefore gives limited information on the warmth characteristics of the blankets. The warmth determinations are very time consuming and are usually repetitious enough to warrant a limited number of test specimens. It is recommended that in any future studies to determine blanket warmth and durability that the
analysis of thickness determinations should be done before any warmth testing is begun. The test specimen with thickness averages nearest to the averages determined for a test fabric could be used for the warmth tests. The findings on thickness, dimensional stability, yarn count, weave, weight and breaking strength would be sufficient to predict warmth. A limited number of warmth tests could then be conducted to substantiate the predictions.

Subjective testing with individuals was considered as effective a determination of warmth as laboratory testing according to Fahnestock and Stout (18). The use of human subjects in testing blanket warmth is recommended by the author in conjunction with the laboratory evaluations and predictions. It is felt that the subjective analysis should give a more meaningful interpretation to warmth testing for the consumer.

Laundering was considered the most satisfactory cleaning procedure for Orlon blankets by Spilker (52, p. 89). She also found that laundering had less effect upon the dimensions of the blankets than dry cleaning. It was determined by Marsh (29, p. T252) that washing lowered the thermal resistance and renapping restored it again to its former value. Shrinkage increased the resistance of the blankets to heat passage because the blankets became thicker.

Laundering is recommended for the cleansing of acrylic blankets because certain dry cleaning solvents may give a harsh
texture to the acrylic blankets. Drycleaning would be the better method for cleaning wool blankets when their dimensional stability is uncertain. However, the dimensions of any blanket may change somewhat as a result of any cleaning process.
BIBLIOGRAPHY


