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A Study of Thermal Insulation and Degradation Due to Heat and Light of Selected Cotton and Glass Fiber Drapery Fabrics Lined and Unlined

Cora Rude Sivers

A STUDY OF THERMAL INSULATION AND DEGRADATION DUE TO HEAT AND LIGHT OF SELECTED COTTON AND GLASS FIBER DRAPERY FABRICS LINED AND UNLINED

BY

CORA RUDE SIVERS

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head of the Major Department

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INTRODUCTION

Drapery fabrics are in much demand today and show an expanding market trend. This expansion is probably due to the more versatile use of draperies in the control of light and heat as well as an increasingly important role in the decor of a room. The need for light and heat control has become important with the advent of the contemporary home and business building where entire walls may be largely composed of window area.

The added quantity of fabric that is required to drape the larger fenestrations today can represent a sizeable investment. Such an investment necessitates a wise choice of fabrics. There are innumerable materials on the market today with a wide choice in fabric construction, color and fiber content. From this array the shopper may select fabrics with reference to: area to be draped; color harmony desired; type of decor and allowable expenditure. The customer can be given information supplied by the manufacturer and retailer. Durability of the fabrics is an important factor and the manufacturer and retailer are striving to give optimum assistance to the customer. Where there are complaints of fabric failure the retailer may send returned merchandise to testing laboratories. Many of these are justifiable complaints. From a 1959 study of the National Institute of Drycleaning, out of 21,709 textile failures only 7916 were traced to defective fabrics or failures of other materials in garments. Of the justifiable complaints, the first was color failure, which constituted 47 per cent of all justifiable complaints; the second was fabric damages, and 39 per cent of these

cases were curtains and draperies that deteriorated from exposure to sunlight and atmosphere. Myers (39) quotes Albert E. Johnson, director of trade relations of the National Institute of Drycleaning who recognized this to be another manifestation of the color failure problem: "In the failure category, sunlight is the major condition causing failure.... It is interesting to note that low resistance of textile fibers to sunlight is the largest single cause of damage complaints of the total complaints received to date, yet no standard methods exist for evaluating the suitability of a textile fiber for the use in window curtain and drapery classification. Nor does the curtain and drapery classification in the ASA (American Standards Association) L-22 Standards contain a reference to a sunlight resistance requirement, doubtless because of testing methods."

The need for fabric preservation from the effects of light and heat has directed this study to lined and unlined drapery fabrics. The effect of lining as fabric insulators was investigated along with the effects of heat and light.

Cotton, glass fiber and metal backed fabrics were selected for this investigation because of their high consumer interest. According to Levine (33), in a marketing research report concerning a nation wide survey of homemakers in 1957, cotton was the dominant household fiber in terms of ownership and preference for future purchase for living-room draperies. About two-thirds of the homemakers in the United States had used draperies in their living-rooms within the year preceding the study; on the average they had 2.6 pairs of living-room draperies. Thus the

31.7 million owners had a total of 82.4 million sets in use during the year preceding the survey. Cotton was found in four homes out of ten; the majority of these cottons, nine in ten, were opaque.

The consumers were aware of the newer fibers, but only two per cent of the homemakers currently owned glass fiber draperies, however some 9 per cent indicated glass fiber as their preferred fiber for the next purchase.

The current decorator magazines for the consumer show a number of adaptable cotton fabrics. The featured window treatments displayed in one magazine were drip-dry cottons, cotton satin, organdy, ticking and Milium backed fabrics (6).

A new concept in draperies is the production of a glass fiber fabric which is said to reduce solar heat transfer as effectively and in some cases better than the accepted shading devices. These draperies for windows also had noise reducing properties (5). Another newer fabric is advertised as Milium metal insulated fiber glass draperies (3).

The drapery fabrics and linings selected for this examination are those available in the average retail store of this general area, namely; Brookings, Sioux Falls, and Minneapolis.

Thermal insulation, thickness, general physical properties and breaking strength, before and after treatment, were measured to secure the necessary data for analyses and interpretation.

A wealth of research has been reported on the thermal insulation of fabrics, much of it for clothing of the United States Army, some of it on civilian clothing but this is not applicable to draperies at

windows except as it related to the fabric per se.

Numerous references are available on research studies relating to the degradation of cotton by light. Studies have been undertaken to evaluate the length of service of sheer curtains and single drapery fabrics. Since none were found which pertained to draperies with linings a study of the salient characteristics of the fabrics, lined and unlined was undertaken and the data were evaluated and analyzed to ascertain the following:

1. How these fabrics, lined and unlined, compared as thermal insulators.
2. Whether certain linings made more effective contributions to the insulation value.
3. How heat and sunlight affect the strength of these fabrics.
4. Whether linings preserve the strength of the fabrics.
5. Whether or not any one lining is more effective in preventing strength loss from sunlight and heat.
6. Whether there is a difference in the degree of colorfastness between the lined and unlined fabrics.
7. Whether cost and durability have a linear relationship.

The analysis of these results may aid in suggesting a more extensive study on the effectiveness of lining drapery fabrics.

REVIEW OF LITERATURE

Degradation of Fabric by Heat and Light

A perusal of the literature reveals extensive research has been reported relating to the degradation of fabrics by light and heat. These reports concern: the chemical change in fabrics due to light and heat; the relationship between fabric properties and degradation by light and heat; various factors influencing the rate of degradation of textile fibers including atmospheric conditions and the use of dyes; the methods which have been employed for measuring light and heat degradation; drapery fabrics that have been studied with reference to light degradation; and improvements proposed for retarding degradation by light and heat including metallic backed fabrics.

Since the early 1920's photochemical degradation has been the subject of a large amount of work utilizing the sun itself or artificial light sources designed to approximate sunlight. Investigators agree that the extremely complex reactions involved are oxidative in nature, but the exact mechanism by which the action takes place is still obscure.

In order for light to cause chemical change in any substance, the rays must be absorbed and be of sufficiently high energy content to change the molecular structure of the irradiated material (27).

Nomenclature

Light is a form of radiation traveling in waves with two characteristic features; amplitude (strength, intensity), and wave length. Wave radiation is a measure of wave length between two peaks of two waves and

expressed in Angstrom units (1 Å. = 10^{-8}cm.) (16).

The scale beginning with radiations of shortest wave length progress as follows: gamma rays, Xray, ultraviolet rays, visible light, infrared and wireless waves. Sunlight contains visible light, infrared and ultraviolet (16).

Terms which relate to the reactions of degradation by light are: photolysis, the disruption of a chemical bond after sufficient light of proper wavelength is absorbed by the fiber, this occurs with the short wave ultraviolet; and photosensitization, a secondary photochemical reaction, the primary action (photochemical) being between the light and the foreign matter present in the textile fiber. An added substance, either as an impurity or added treatment, can absorb light and shift the effective light range limits. This second substance, the sensitizer, carries the absorbed energy to the reacting molecules of the fabric (45) (16).

Langley units are solar intensity measured in terms of grams calories per square centimeter per minute. If solar radiation continues for 60 minutes at an intensity of 1 gm/cal/cm^2 then a sample under exposure receives 60 langley units (45).

One Standard Fading Hour in the Fade-Ometer equals 90 langleys. It now appears that one Standard Fading Hour in the Fade-Ometer produces a degree of fading comparable to an outdoor exposure of 80-100 langleys.

Another measurement now believed an accepted rule is: 90 Fade-Ometer Hours are approximately equal to 100 sun hours in Florida for

conditions under which this measurement was originally developed and used. For this purpose standard Fading Hours mean hours in the Fade-Ometer, and hours in Florida means exposure on sunny days between 9 A.M. and 3 P.M. as called for by the old Standard A.A.T.C.C. (American Association of Textile Chemists and Colorists) Sunlight test method (40).

The Eppicy Pyrheliometer is an instrument which measures solar intensity in terms of grams calories per square centimeter per minute. The energy gathered on the receiving surfaces is converted into electrical energy and registered in millivolts on special recorders (45).

Photons are light bundles of energy (13).

Chemical Change in Textiles Due to Light and Heat

The extent of the chemical change produced depends on the frequency of the radiation absorbed. Higher frequencies (shorter wave lengths) produce a greater change because they furnish greater amounts of energy per unit of radiation (27).

The sunlight reaching the earth consists of a continuous spectrum of radiant energy having wave lengths between 3,000 and 50,000 Å. About 45 per cent of this light lies between 4,000 and 7,000 Å. and is visible to the eye as white light. Radiant energy having wave lengths longer than 7,000 Å. is invisible and is found in the infrared region. These tend to warm and are considered radiant heat. Shorter wave lengths 3,000 Å. to 4,000 Å., are invisible and called ultraviolet constituting about 5 per cent of the total sunlight (13).

Ultraviolet photons have more energy than many molecular bonds in organic compounds. When absorbed by a molecule the photon can

initiate chemical reactions that can be considered as photo degradation. Experimentally photo degradation has been reported to be caused by energy from both the ultraviolet and visible wave lengths of light (13).

The ultraviolet region with wave lengths between the limits of 2,500-4,000 Å. is the most degrading to untreated textiles. The rays of this region possess high energy content per unit of radiation, and their absorption by cellulose produces more rapid degradation than equal periods of exposure to other parts of the spectrum (27).

Egerton (17) has postulated a mechanism of action based on the theory that effects obtained depend upon the region of ultraviolet in which exposure is made. In the short wave ultraviolet region, around 2537 Å., the effect is one of photolysis in which the light absorbed by the cellulosic material produces a disruption of the carbon-carbon and carbon-oxygen bonds. This action can take place in the presence or absence of oxygen. In either instance, upon subsequent exposure to oxygen the degradation products may undergo further oxidation. This process can also occur in the near ultraviolet (3,400 Å.) and the visible range (4,000-7,000 Å.), but at a reduced rate, since smaller amounts of energy are received by the cellulose.

Light is believed to break the molecular chain of cellulose into shorter units and to weaken the glucosidic linkages so that they are readily attacked and ruptured by oxygen (27)(16).

Relationship Between Fabric Properties and Degradation by Light and Heat

Fiber

The nature of the fiber affects the rate of degradation. Some fibers are more sensitive to light than others. Wool appears to have less strength than cotton and linen but more than nylon or silk; acetate and glass fabrics are the most durable according to a study by Fletcher (19) on the effect of light and heat on drapery fabrics. Kaswell (29), commenting on this same study notes one should consider the fact that the fabrics are not all of the same weight, and since the light exposure test in particular is a surface reaction, the per cent loss in strength or elongation cannot be accepted as an absolute criterion. Also a stronger fabric (e.g., nylon) may lose more of its original strength after exposure, and still retain more absolute strength than a weaker fabric which lost little or no strength.

Appleby (7) after a thorough search of the literature on the action of light on textile materials concludes that regarding strength retained wool is placed in the top position and silk at the bottom, the other fibers falling between these boundaries. She uses per cent loss in strength as a criterion.

Yarn Construction

According to Howard and Mc Cord (27) it has been shown that such factors as yarn twist, yarn crimp, ply, and weave have an important bearing on the amount of degradation which occurs to fabrics upon exposure to light. They noted that heavy fabrics, closely woven from highly twisted yarns, are the least deteriorated by light. The finer the yarn and the looser the construction, the less resistant a fabric is to sunlight (4).

Fabric Structure

Construction influences the drapeability of the fabric. This can be a factor in drapery fabric deterioration as it was noted by Chu, Platt and Hamburger (11), that improved drapeability was found in acetate and cotton fabrics where weaves with longer floats reduced cover factors and decreased yarn diameters. Yarn twist and fiber cross-sectional morphology were also seen to be influential factors in determining the draping characteristics of a fabric.

Factors Influencing the Rate of Degradation of Textile Fibers

Temperature

Degradation seems to be greater at higher temperatures. According to Egerton (16) heat will degrade cotton by increasing the rate of chemical reactions. Robinson and Reeves (44) compared Fade-Ometer test results with results obtained in sunlight and found, in general, an increase in temperature had much more effect on both fibers and dyestuff than did an increase in relative humidity.

Temperature and moisture were factors contributing to a higher color change in specimens tested by the Sun-Hour exposure method using the Eppicy Pyrheliometer. In the three methods employed samples $2\frac{1}{2}$ x $2\frac{1}{2}$ inches were mounted and placed three inches from glass. One method exposed the samples for 24 hours a day under glass. Another method exposed the samples from 9 A.M. to 3 P.M. under glass on sunny days, the cabinet being covered otherwise with the samples left in. The samples in the third method were exposed from 9 A.M. to 3 P.M. under

glass, then removed and stored in a cool place.

The covered samples had 12 per cent more color change than the cool stored ones. The uncovered samples had 34 per cent more color change because they received a higher number of langleys, 4864 langleys. The uncovered samples received 29 per cent more langleys than the covered and stored ones.

The uncovered samples had 34 per cent more color change with 29 per cent attributed to radiation and 5 per cent increase in color change mentioned as undoubtly due to other factors, which may include specimen temperature and moisture content.

The covered samples and those which were removed received the same amount of radiation but the covered produced 10 per cent more color change than the removed. Norton and committee (40) concluded that it must be caused by leaving the samples in the cabinet. The explanation for this was based on the theory that fading is associated with, and increases with a rise in temperature and that the fading action from absorbed radiation does not cease the instant the swatches are covered, but apparently continues if the fabric temperature is not reduced. When leaving the specimens in the cabinet overnight they absorb moisture which causes them for a period of time after the covers are removed each morning to be exposed to radiation while at high moisture content.

Certain fibers appear to be more heat resistant than others in referring to Fletchers' (19) study, previously mentioned. After 200 hours of progressive exposure to heat up to 125 degrees centigrade the

per cent of strength remaining for each fiber was: glass 105.6; acetate 102.5; wool 88.6; viscose 79.8; and cotton 72.1.

Schmitt (45) mentions that Seibert and the Chicago section of the American Association of Textile Chemists and Colorists have shown that temperature greatly increased the fading rate.

Humidity

An increase in humidity usually increases degradation although the effect depends upon the nature of the fiber (16). The sensitizers absorb the light and cause a reaction changing the water or oxygen present either to hydrogen peroxide or ozone. These, in turn, react with the cellulose in a straight chemical reaction which degrades it (44).

Fade-Ometer and sunlight tests in the study of Robinson and Reeves (44) used three relative humidity ranges namely: 35 per cent, 50 per cent, and 65 per cent. It was found as reiterated here that an increase in the temperature had much more effect on both the fibers and dyestuffs than did an increase in humidity.

It is indicated by Schmitt (45) that moisture is only a contributory part of abnormal fading, both in depth and shade change. He contends that when a fabric becomes moist in the evening, various materials from the atmosphere are absorbed. In the wet state, these contaminants react on the dyestuff within the fiber. As the temperature rises during the day these contaminants become concentrated and very active and greatly increase the fading rate.

Industrial Fumes

The presence of industrial fumes e.g., sulfur dioxide will lead to degradation, not photochemical (16). Howard and Mc Cord (27) contend degradation by corrosive acids is a factor in highly industrialized areas, but just how much a factor is not known.

Dyes

Certain dyes and pigments reduce light degradation by reflecting or absorbing harmful wave lengths, while others accelerate the deterioration process (27). Egerton (16) says the dye seems to be able to pass the absorbed light energy on to effect a destruction of the fiber molecules. The sensitizing dyes do not belong to one particular class but it is most frequently observed with the fastest-to-light dyes viz., vat dyes, on cellulosic materials. This sensitizing is more marked among yellow, orange and red color ranges. Howard and Mc Cord (27) also mention vat dyes as being the first recognized as sensitizers of photochemical degradation. Vat dyes absorb radiation very strongly in the far ultraviolet, particularily in the region around 2537 Å. (17).

Direct dyes on cotton produce much lower ratings on many dyes in the Fade-Ometer run at 165° F. than sunlight (45).

Certain white pigments (zinc oxide, zinc sulfide and titanium dioxide) which may be used as delustering agents have the property of sensitizing the photochemical degradation of textile materials notes Egerton (16). Howard and Mc Cord (27), Kleinert and Mossmer (30), Lang, Treiber and Mader (31) also refer to the delustering agent, Titanium dioxide, as being damaging to the cellulosic materials upon exposure

to light.

Dull and semi-dull yarns are less resistant to light than bright or shiny yarns, the degree of tendering increasing with the fiber fineness (4)(30).

Usually the intensity of the color of dye is reduced but with some dyes the color may darken on exposure says Egerton (16). Very often fading of the dyed material is observed more readily than is the somewhat hidden attack of sunlight upon the textile substrate.

Schmitt (45) reports the public has become more cost conscious with the increase in the cost of textiles and expect better quality in their textiles. The drapery trade started asking for 80 hours lightfastness on pastel shades on cotton or cotton-viscose materials. They were able to accomplish this by judicious combinations of selected new dyes; and on some of the popular bark fabrics they obtained 120-140 hours before a break.

Methods for Measuring Fabric Degradation

Due to the need for completing light tests in the shortest possible time most light testing in the United States is done in the Fade-Ometer of which there are over 2000 in daily use according to Schmitt (45). An advantage of the artificial source of light is that tests can be run 24 hours a day. The Fade-Ometer employs the carbon arc as its light source (27). The glass enclosed carbon arc is of lower intensity than the open high intensity carbon arc which requires frequent attention as the electrodes burn at a considerable rate (32).

Howard and Mc Cord (27) report that of the available light

sources, the high-intensity carbon arc with appropriate filters seems to give the most reproducible results. With a special glass filter, its spectral characteristics closely approach those of natural sunlight. The spectral range of a corex-enclosed carbon arc is approximately 2,900-40,000 A., as compared to a range of approximately 2,900-30,000 A. for sunlight at sea level.

The mercury vapor lamp is a second artificial light source used to study the effects of the sun's rays on fabrics. Its spectral range is 1,800-14,000 Å., with an especially strong distribution in the ultraviolet range. One of the disadvantages of this lamp is the production of ozone, which may cause inaccurate results (27).

There are two main methods of using a fading lamp. One method consists in exposing standards together with the sample to be measured and expressing the fastness by reference to the standard. The other method consists in using the standards to calibrate the fading lamp, and then expressing fastness in terms of number of hours required to produce a given degree of fading. This is the method specified by the U. S. Department of Commerce, C. S. 59. The U. S. Department of Commerce has issued calibration papers which can be used to calibrate any fading lamp in terms of the master lamp in the U. S. National Bureau of Standards (32).

Morton (38) relates that M. Dufay controller of the French dyeing trade in 1733 established basic principles of light-fastness testing which are still regarded as valid. Samples were exposed to sunlight for a given time and compared with a standard sample.

Some recent studies using the Fade-Ometer as their method of measuring service qualities of draperies and curtain fabrics are:

(1) Cooper (14) found that despite vast improvements made in dyes more consideration needs to be given to the selection of dyes for drapery fabrics if the consumer is to receive satisfactory performance from them as to color fastness to light.

(2) Fletcher (20) in predicting the wear-life of sheer curtaining materials used a mathematical approach to predict the life expectancy of curtain material. An equation showed the relationship between time of exposure and any given breaking strength.

(3) Cormany (15) evaluated some of the service qualities of sheer curtains and concluded that sheer curtain fabrics made of cellulose fibers tend to be less satisfactory when subjected to light and laundering than are fabrics made of the resin or glass fibers.

(4) Teirney (51) studied the performance and wear-cost ratio of drapery fabrics for dormitory rooms and noted the lower priced cotton fabrics had the best all-round performance.

Solar exposure is also used for light testing. This is usually exposure under or behind glass often at a distance of three inches. The fabric is usually mounted flat in a frame. Cormany (15) used this method in a three year study of curtain fabrics behind windows. Norton and Committee (40) employed the use of a cabinet with the samples under

glass.

Howard and Mc Cord (27) mention that ordinary glass screens out ultraviolet radiations below 3400 Å., therefore special glass with transmission characteristics similar to the spectrum of sunlight could be used to cover exposure cabinets. Lead (32) points out that ordinary window glass passes some ultraviolet as far down as 3200 A. and has a very high transmission in the immediate ultraviolet, where the main output of the enclosed carbon arc lies. It has been found that some dyes actually fade faster under ordinary glass than under no glass at all, or under corex, which passes all of the ultraviolet present in sunlight. The suggestion has been made that a photochemical action produced by light of one wave length can be counteracted by light of another wave length.

The Sun Hour method or any natural light cannot be valid in which exposures are expressed on the basis of time only. In natural light exposures the greatest contributing factor in the amount of color change produced is total amount of radiation received. Langley units which integrate time and intensity of radiation as grams calories per square centimeter per minute appear to be a satisfactory measure of total radiation received. The best figure to use for comparison with the Fade-Ometer is: 90 langleys equal to one standard fading hour in the Fade-Ometer (15)(40).

Damage to textiles can be measured in various ways, such as breaking strength loss, cuprammonium fluidity, methylene blue number, tearing strength, and others. Tendering of a fabric is usually measured by

the breaking strength or fluidity measurement. Breaking strength measures the ability of a fabric to resist rupture when placed under tension, whereas fluidity is a measure of the breakdown of the cellulose chain length, since it measures the average degree of polymerization (44).

Methods for Lessening Degradation by Light and Heat

Recent investigations have shown that mercerized cotton is more resistant to sunlight and to weathering than unmercerized cotton. So far, no specific explanation has been given for the better weathering qualities of the mercerized fabric, which may have one-third to one-fourth longer service life than an untreated cotton fabric. Spectrophotometric measurements show that a mercerized cloth has less reflectance and greater transmittance than an unmercerized sample (27).

Coleman and Peacock (13) in a study of screens to absorb ultraviolet light and protect dyed textiles, concluded any screen that removed both the ultraviolet and a portion of the visible spectrum must be colored.

Cotton fabrics coated with various sulfonylamino derivatives have been found to withstand sunlight exposure much better than untreated cloths (27). Reeves (42) has shown that it is possible to attach an antioxidant chemically to the cellulose.

Jolly (28) reports that the Milium Company researchers hope to establish that aluminum coating on the reverse side of draperies will give the draperies greater fading resistance than similar untreated fabrics.

Caroselli (10) says plasticized vinyl resin derivatives are now being used to coat and color glass fiber drapery fabrics. This treatment gives superlative light fastness to colors and increased tensile strength to the yarns.

Thermal Insulation of Fabrics

Ancient writings have made it clear that differences in thermal insulation between fabric materials have been recognized for many centuries according to Marsh (34). Linen has always been regarded as cool and wool as warm. He states the original object for which fabrics were made was clothing; and the principal factors in choosing clothes are appearance and their property of acting as suitable thermal insulators. Therefore appearance and thermal insulation are considered the most important properties of a fabric.

Thermal insulation has been the subject of considerable research since the beginning of this century. The majority of these studies concern properties of textile fabrics which contribute insulating qualities to clothing or blankets. Reported in these studies are the nature of heat transfer; factors which influence thermal transmission; the relation of metallic backed fabrics to thermal insulation; the relation of double fabrics to thermal insulation; and methods for measuring thermal transmission.

Nomenclature

Thermal conduction in classical physical terminology is defined by Hardy (25):

"In a medium with uniform physical properties, it has been demonstrated that the amount of heat which flows from a warm surface to a cool one is directly proportional to the length of the path, the nature of the medium, and the thermal gradient:

$$H_D = \frac{KA\ (T_2 - T_1)\ \ X}{d}\ t,\ \text{gm. cal.}$$

Where

H_D = quantity of heat conducted

K = thermal conductivity constant

A = area of the conducting surfaces

T_2 and T_1 = temperatures of the warm and cool surfaces

t = time

d = thickness of the conductor."

According to Skinkle (48) the thermal conductivity of any material is given by the formula $C = \frac{k}{L}$

where

C = conductance of the particular sample

k = thermal conductivity per centimeter of thickness

L = thickness of material

If the coefficient k is desired, the thickness must be measured and $k = CL$.

Nature of Heat Transmission

Heat may be transferred from one place to another by one or a combination of three ways, conductance, convection and radiation. Conductivity refers to conduction or a combination of all three. It is important to bear in mind the fact that air is a poor conductor of heat. Fabrics, to be poor conductors of heat, must be capable of holding large

quantities of trapped air within their structures.

Heat transfer by convection involves the actual motion of the heat carried from one place to another. Hot air readily is moved from one place to another and resulting convection currents are a means of transfer of quantities of heat. Air may move through fabrics, depending upon their permeability to air. Much of the heat transmission through fabric takes place in this fashion.

Heat may be transferred by radiation and may take place even though there is a vacuum. Heat from the sun reaches us by this means. Heat travels in straight lines much like light. Thus the more broken up or interrupted the path along which radiant energy travels the more difficult the passage will be and the less heat transmitted. The importance of this fact is evident when the structure of fabric is considered (46)(50).

Thermal conductivity does not have its usual precise significance when applied to a heterogeneous system such as a fabric. Not only is the transfer of heat accomplished by convection and radiation as well as conduction, but measurements of one of these factors, convection, may vary considerably according to the design of the apparatus used. Results of the greatest value will be obtained when the apparatus is so designed that the convection factor operates in much the same way as when the fabric is actually in use (50).

Factors Influencing Thermal Transmission

Fabric Structure

If a piece of cloth is used as a vertical covering to separate a volume of warm air from a volume of cold air, heat may pass through the fabric from the warm side to the cold side by the three methods noted. If between yarns there are openings which extend through the cloth then convection currents are easily set up and warm air passes through the apertures carrying heat with it.

Since the fibers of which the fabric is composed make contact in numerous places to form fabric, heat flows by conduction through one fiber to another where there is contact. Textile fibers are not particularly good conductors of heat, often because of inclusion of large amounts of air, and sometimes by reason of lack of dense chemical structure. Thus the part played by inter and intra-fiber conduction of heat in cloth is small. The kind of fiber is important in the matter of thermal properties of the fabric only in so far as it can create and maintain dead air spaces in cloth. These form the real barriers to heat flow.

Since air is not opaque to radiant heat energy, heat may be transmitted by radiation. Cloth openings afford straight line passage from one side to the other, thus radiant heat can pass through fabric readily. If the passages are tortuous or interrupted, then heat has to be absorbed by the fiber, radiated to surrounding air or transmitted to a contacting fiber, again radiated and so on until it has passed completely through the goods. Since radiant heat travels at a speed of approximately 187,000 miles per second, it does not take long for heat to pass from one side of the fabric to the other.

It is recognized that fabric depends largely upon the number, size and arrangement of air spaces for its insulating value. The fibers and yarns of a fabric may then be considered as a more or less efficient framework for the production and retention of a number of dead air spaces. The term dead air space precludes the possibility of convection directly through the fabric. It is usually not possible in fabric construction to ensure that all of the spaces formed will contain still air. It is rather attempted to so construct material that the motion of air from one space to another will be greatly restricted as to velocity and amount (46).

Freedman (22) concluded in his study on blankets that: the higher the yarn count, the greater the thermal insulation; the finer the wool fiber, the greater the thermal insulation; the plain weave does not provide as much warmth as do the lock, twill and crepe weaves; and thermal insulation is increased in general by successive nappings, although there will be a limit to the number of nappings.

Thickness of Fabric

Marsh (34) reports on the thermal insulation value of wool and worsted suitings, wool overcoatings, flannels, wool and cotton blankets, cotton knit goods, acetate fabrics, cotton duck, linens, cambrics, silk taffeta, crepe de chine, and wool felt. From these analyses of data he plots thermal insulative value (T.I.V.) vs thickness and shows that the relationship is substantially linear.

Rees (41) states, "Thickness may not be the only factor which determines the thermal insulation of a fabric, but it certainly is one

of the most important."

Fourt and Harris (21) report that Schiefer and others, comparing 156 blankets of various materials and thicknesses and some thirty or more knit underwear fabrics, found that the resistance could be quite accurately calculated from the thickness.

<u>Density and Air Permeability</u>

Other factors than thickness are important to the thermal insulating power of a fabric. Density and air permeability are important and these depend not only on the choice of fibers, but also on the choice of textile structure factors such as tightness of twist in yarns, spacing of yarns in weaving, formation of a pile by weaving, or raising loose fibers by napping or brushing. Once a given textile structure is decided upon however, its effectiveness is largely determined by the type of fiber used (21).

Rees (41) said, generally, fabrics of low density had a smaller heat loss. Some fiber densities in grams per cubic centimeter are: wool 1.32; cotton, linen 1.50; and glass fiber 2.56 (48). Morris (35) states measurements of thermal insulation of fabrics have shown that the still air contained within a fabric is primarily responsible for the good thermal insulation obtained. Increasing thickness and decreasing density have been found to increase the thermal insulation of fabrics.

Two fabrics nominally of the same density may differ markedly in their structure. One fabric may consist of loosely woven, tight, hard yarns and the other may be closely woven from soft yarns. It is thus

possible to obtain considerable variations in the thermal transmissivity of a fabric although its density and most other factors are the same (35).

<u>Weight</u>

Two fabrics may have the same thickness and the same thermal conductivity, but in obtaining such equal thicknesses, different amounts of fiber may have to be used. That is, aggregates of different fibers may have different bulk densities, consequently one fabric may weigh more than the other (35). Marsh (34) found very poor correlation between thermal insulative value and weight per unit area.

<u>Porosity</u>

According to Burleigh et. al. (9) porosity of a textile fabric pertains to the total volume of void space contained within its boundaries. Permeability refers to the accessibility of the void space to the flow of gas or liquid. The total interfiber and interyarn porosity is dependent upon such variable construction features as fiber fineness and shape, type of weave, number of yarns per inch and yarn twist.

Robertson (43) states, "It is evident that the twist has a profound effect on the fabric porosity (permeability). This is probably a direct result of the effect of twist in compacting the fiber bundle and the resulting high yarn densities with high twist. For a given fabric, no other variable was found to have nearly as great an effect on porosity."

Clayton (12) says it is conceivable that two fabrics may have the

same permeability for very different reasons. A thick fabric with an open weave may have the same permeability as a thinner cloth with a closer weave.

Humidity

Rees (41) mentions the effect of humidity on the loss of heat through fabric as being substantially negligible.

Surface Character

In addition to thickness and density, fabrics differ from each other in character of surface. This results from both structural factors introduced in weaving or knitting, and from the choice of fibers in the yarns (21).

Baxter and Cassie (8) show that a rough surface gives a low surface emissivity compared to a relatively smooth fabric. They state that smooth surface fabrics have high emissivities which produce high heat transfer from fabric to fabric.

Gregory (24) examined 21 fabrics used in the tropics and made the general conclusion that a high reflection factor results from a very closely woven and smooth surface. The more uneven a surface is, the less chance the reflected heat has of an unobstructed path away from the fabric. Two fabrics, sateen and acid-treated drill which showed the highest reflecting power had smooth, closely woven surfaces. He mentioned that a high reflective power is wanted in fabric for radiant energy from the sun.

The energy of sunlight falling on fabric is partly reflected and

partly absorbed. The absorbed energy warms the cloth until a balance is established between the rate of absorption and the rate of dissipation of energy by re-radiation. The re-radiation of energy takes place at the long wave lengths (infra-red) (21).

Metalized Fabric

The metals are the only materials which show high reflection of radiation through the infra-red region. The effect of metals on radiation is two-way; the metals not only reflect the radiation, but also prevent the emission of infra-red. The metallic surface can act as a barrier only if it is exposed, so that energy is free to leave or attempt to enter as radiation. The metal offers no barrier to the passage of heat in the form of molecular motion, that is, to conduction; it is a barrier only to the conversion of energy from one form to the other (21).

If the metal is lacquered to protect the surface, this film forms a highly emissive surface if lacquer is more than about one micron thick (21).

Herrington (26) says an aluminum surface must either be uncoated for long-wave infra-red insulation or be so thinly coated that the effect of the organic materials is unimportant.

Fourt and Harris (21) present data collected during World War II in which the thermal insulation values were higher for metalized cloth with the metal side away from the heat source.

The achievement of a light-weight, strong, vapor-permeable fabric with a highly reflective surface requires the best combination of

metal and textile. Fourt and Harris (21) noted that for the infra-red barrier vacuum deposited aluminum gave the highest reflectivity and had the best fabric properties of the several types of combinations considered, namely: continuous layers of metal; lame; tinsel-metal ribbons wrapped around yarns; metal powder mixed with plastic and coated on cloth; and metal powder adhering to the surface of coated cloth.

According to Jolly (28) the Milium process consists of spraying one side of a fabric with resinated metal. Any metal flakes, even gold or silver, can be used in the new finishing process but aluminum appears to be the most economical. Fabrics of any ordinary natural or synthetic fiber can be treated.

Concerning the metal used, Herrington (26) says, a good reflector for energy from a high temperature source is not necessarily a good reflector for the dark heat from our ordinary surroundings. An aluminum surface is one of the most common reflectors for high-temperature sources and is also a good reflector for the dark or invisible infra-red radiation if surface coating reservations are adhered to.

Less than an ounce is added to the weight of a coat lining by the Milium process and there is no interference with porosity according to Jolly (28). One test, confirmed independently by the U. S. Testing Co. in its Hoboken, New Jersey laboratories, found that fabrics which have been Milium-treated show a decrease of up to 46 per cent in radiant heat transmission.

Morris (36) in a summary statement concerning coat linings said the plain satin lining fabric had significantly higher thermal insulation

value than had the metalized satin lining, but all values were approximately of the same numerical magnitude.

The Effect of Layers of Fabric on Thermal Insulation

The most perfect insulation, based on flexibility and minimum weight, consists of small laminations of dead air. The air layers when controlled approach their optimum insulation efficiency at a thickness of one-quarter inch. Greater widths of dead air space decrease their insulation value due to the development of small convective currents caused by air rising on the warm side of the air cell and settling along the cold side of the cell. This forms a circular motion which rapidly increases the rate of heat exchange between the two walls (47).

The Army's widely publicized "layer principle" of clothing is a lamination of thin or loosely woven materials separated by layers of dead air (47).

Rees (41) says the addition of successive layers of the same material will naturally increase the thermal insulation. Results of his study showed that with a cotton fabric the T.I.V. per cent with one layer was 35.2, with two layers, 67.5, and with three layers, 76.6.

Rees (41) combined a typical wool blanket with a thin linen cloth and found the T.I.V. of the combination was 76.0 per cent while the T.I.V. of the single blanket was 73.3 per cent. He also combined a cellular wool blanket with the same thin linen cloth and received a thermal insulative value of 74.0 per cent whereas the single layer of the cellular wool blanket had a T.I.V. of 64.8 per cent. The cellular sample had poor insulation value owing to air being circulated in its

open structure, when this air was immobilized within the fabric by the linen cover the T.I.V. was greatly increased.

Morris (35) stated the thermal insulation of fabrics is considerably increased if covered with a fine closely woven outer fabric.

Morris (36) in a study of the insulation value of fabric combinations, said combinations of fabrics may actually contain more air per unit area than would be indicated by combining the measured values for the single fabrics because of the air enclosed between the fabrics in the combination.

Linear regression lines, representing the relationship between thermal insulation and other properties, for the single fabrics give lower estimated values than do those for the multiple layers of fabrics. Therefore, accurate estimates of thermal insulation for multiple layers of fabric may be made only from equations based on measurements of such combination stated Morris (37).

Methods of Measuring Heat Transmission

Three common methods for measuring the thermal transmission of fabrics (29), (34), (48) are:

(1) Disc or Plate Methods. The fabric is held between two plates at different temperatures and the rate of flow of the heat through the fabric is measured. Precautions must be taken in this method to control fabric thickness and the pressure must be stated if the results are to be reproducible.

(2) Cooling Method. A hot body is wrapped with the fabric and

its rate of cooling measured. The outer surface of the fabric is exposed to the air, and is not in contact with any solid substance.

(3) Constant Temperature Method. A body is wrapped with the fabric and maintained at a constant temperature by a controlled supply of energy (usually an electric heater).

Marsh (34) says the advantage of the constant temperature method lies in the fact that the measurements of heat are replaced by those of electrical energy and can therefore be made more accurately. Skinkle (48) reports this method has been used by Haven, the Bureau of Standards, Marsh, and Angus in making very accurate comparisons of thermal insulating values.

Wing and Monego (52) comment on the method adopted by the Quartermaster Corps and generally referred to as the "guarded hot plate" similar to the method developed by the National Bureau of Standards. The hot plate setup is complicated and cumbersome in practice and does not commend itself to industry or to the smaller laboratories. Specimens are placed on the flat horizontal hot plate about 20 inches square in a conditioning chamber maintained at a constant temperature. The electrical energy required to maintain the surface temperature as heat escapes through the fabric is subtracted from that needed when the plate is bare, the difference being used to compute the insulative effectiveness of the specimen. The hot plate is useful and fairly dependable for fabrics with thicknesses greater than 0.11 inches.

Skinkle (48) states the disc method using the Fitch thermal conductivity apparatus is perhaps the most commonly used for testing

heat transfer properties of fabrics. Wing and Monego (52) state the Cenco-Fitch apparatus is quite rugged, inexpensive and fast but somewhat neglected as a test instrument. They concluded the Cenco-Fitch data are very reliable and reproducible for fabrics in the 0 to 0.5 inch thickness range.

Fahnestock and Stout (18) employed an "unguarded" hot box designed for use in measuring the insulative property of blankets. It was a 23 x 23 x 23 inch insulated cardboard box designed to maintain a constant inside air temperature when its open top was covered by a lid or by the blanket specimen. The box was equipped with thermostat, watt meter, and thermometers, and was maintained at a constant inside temperature of 97° F by means of a 25-watt light bulb placed in the floor of the box. Since the blankets varied in thickness, in order to compare insulative quality, the watts per hour were based on the same blanket thickness.

METHODS AND MATERIALS

The resistance to light and the insulative value of selected drapery fabrics were studied through measurements of thermal insulation and light degradation before and after treatment. The drapery and lining fabrics and combinations of these fabrics were those often used for draperies at windows. The single fabrics were measured to ascertain additional properties descriptive of their construction.

Procedures for the measurements of most of these properties are standard methods (1) (2). In one instance a published method of procedure and apparatus was modified to more nearly simulate the actual situation desired for this purpose (18). All physical measurements, except for color fastness and thread count, were made under standard atmospheric conditions (65 per cent Relative Humidity and 70° F., plus or minus 2 per cent and 2°, respectively). To insure the fabrics' moisture equilibrium with the standard atmosphere they were hung to condition at least 12 hours in the conditioning laboratory before laboratory measurements were made.

Fabrics

The fifteen fabrics selected for study varied in fiber content, weight and construction, and were of the type commonly used for draping windows. Three textured cotton, two drip dry cotton, two chintz, four glass fiber fabrics and four cotton linings were included. These fabrics were purchased on the retail market in the local area in 1960. The fiber content was recorded from fabric labels when the purchases

were made. The description of these fabrics is given in Table 1, page 35, and swatches are shown in Exhibit I of the Appendix. Combinations of the drapery fabrics and linings used in this investigation are specified in Table 2, page 36.

Sampling

Three to five samples were cut from each of the fifteen fabrics for each property measured. Samples were cut from different areas of the total yardage to assure dissimilar warp and filling yarns. No samples were cut beyond a 3 inch margin on either selvage. Different samples from the same yardages of fabric were used for the single and double layer combinations, as shown in Table 2. Measurements were made on these for thermal insulation, colorfastness and breaking strength.

Laboratory Measurements

Fabric Count

Fabric count was made on the 15 fabrics at 3 different positions on the total yardage and no count taken closer than one-tenth of the width of the fabric. The number of warp and filling yarns in one inch was counted with a micrometer counter and pick magnifying glass. The mean of the three measurements in both the warp and filling directions was reported as fabric count.

Thickness

The Compressometer developed by Schiefer and described by Fourt and Harris (21) was used for measuring thickness. A presser foot one

Table 1. Purchasing Data for Cotton and Glass Fiber Drapery Fabrics

Code	Fabric	Fiber	Width as purchased in inches	Price per linear yard	Price per square yard	Source
CT 1	Textured	Cotton	45	$ .98	$ .81	Local chain dept. store
CT 2	Textured	Cotton	48	2.29	1.71	City dept. store
CT 3	Textured-damask	Cotton	45	2.95	2.34	Local furniture store
CD 1	Drip-dry	Cotton	36	1.14	1.14	Local chain dept. store
CD 2	Drip-dry	Cotton	36	1.85	1.85	City dept. store
CC 1	Chintz, glazed	Cotton	36	.59	.59	Local chain dept. store
CC 2	Chintz, glazed	Cotton	36	.79	.79	City dept. store
GO 1	Opaque, pattern	Glass fiber	40	1.49	1.44	Local chain dept. store
GO 2	Opaque, pattern	Glass fiber	40	1.49	1.44	Local chain dept. store
GM 1	Marquisette	Glass fiber	40	1.44	1.26	Local chain dept. store
GM 2	Marquisette	Glass fiber	42	2.50	2.07	City Dept. store
LC	Chintz lining	Cotton	36	.59	.59	Local chain dept. store
LM	Milium on sateen	Cotton	50	2.40	2.16	Local furniture store
LU	Muslin-unbleached	Cotton	39	.32	.27	Local chain dept. store
LS	Sateen	Cotton	45	1.10	.90	Local furniture store

Table 2. Combinations of Cotton Drapery Fabrics and Linings Used in this Investigation

Drapery	Linings			
	Metalized sateen	Unbleached muslin	Chintz	Sateen
CT 1	X	X		X
CT 2	X	X		X
CT 3	X	X		X
CC 1			X	X
CC 2			X	X

inch in diameter with a pressure of 1.00 pound per square inch was used. The foot was gradually lowered and allowed to rest 5 seconds before the reading was taken. The mean of the values of the 3 measurements on each fabric was recorded to the nearest .001 of an inch as the thickness of the fabric.

Weight

Five samples two inches square were cut from each fabric with a die and weighed on a 5 gram capacity Roller-Smith precision balance to the nearest .001 of a gram. The mean of values for the five samples was converted to ounces per square yard and recorded as the fabric weight.

Yarn Number

Forty yarns 10 centimeters in length were cut from each sample. To assure accuracy in cutting samples the yarn was carefully raveled

from strips of fabric and measured on the Suter Twist testing device under tension of 0.25 grams per Tex. Each yarn was weighed in milligrams on a Universal Yarn Numbering Balance. The mean values for each fabric were converted to grams and reported as Tex units.

Fabric Strength and Elongation

Strength and elongation measurements were made on specimens cut 1½ inches wide by 7 inches long and raveled to a width of one inch by removing approximately the same number of lengthwise yarns from each side. Three warpwise breaks were made on each fabric.

A pendulum type, motor-driven breaking strength machine, equipped with an autographic recorder was used, operating with a uniform speed of 12 ± ½ inches per minute. The load capacity used was 150 pounds.

The faces of the clamps used on the machine measured one by two inches and the distance between the clamps at the beginning was exactly three inches. An initial load of six ounces was placed on the specimen to assure uniform tension and faciliate alignment before tightening the lower clamp.

The mean values of three determinations was recorded in pounds as the breaking strength of the fabric.

The elongation of the fabric under stress was obtained by means of an autographic recording device on the breaking strength machine. Readings were recorded to the nearest one-hundredth of an inch and calculated from the point indicating the first application of stress to the point indicating the break. The mean of the three determinations was reported in per cent elongation.

Colorfastness

The Gray Scale was used in measuring colorfastness of specimens to light after exposures of 100, 200 and 400 hours in the Fade-Ometer. The Gray Scale consists of five pairs of chips each representing a rating from one to five on the scale. Fastness rating number five has identical chips of neutral gray with a color difference of zero. Ratings numbering from one to four have visual gradations in geometric steps of color difference, each paired with a chip of neutral gray. The fastness rating of the specimen is reported as that number of the Gray Scale which corresponds to the contrast between the original and tested specimens.

The mean values for three samples was recorded as the colorfastness number for each fabric.

The Fade-Ometer, containing a glass-enclosed carbon-arc lamp, was used to produce fading and fabric degradation. Three specimens from each fabric and combination of fabrics were exposed for 100, 200 and 400 Standard Fading Hours.

The apparatus consists of a vertical carbon arc mounted at the center of a cylindrical shell and enclosed in a clear pyrex glass globe. A cylindrical frame between the arc and the shell supports specimen holders which position the 2½" by 3" specimens so they face the arc at a distance of ten inches from the center. This frame with specimens revolves about the arc 2 to 4 times per minute.

A blower unit thermostatically controlled by the ambient air temperature provides a flow of air over the specimens and through the

test chamber. The air is filtered and humidified by circulation over wicks saturated with water.

The machine was adjusted so that it produced approximately 20 Standard Fading Hours in 20 clock-hours of operation at a Black Panel Temperature of $165 \pm 5^{o}F$. Light-sensitive paper was mounted in a specimen holder and placed in the lamp every 20 hours for an estimate of the exposure in Standard Fading Hours. The light-sensitive paper was compared with a booklet of standard faded strips obtained from the National Bureau of Standards for calibration of fading lamps.

Thermal Insulation

The modified Fitch thermal conductivity apparatus was one type of apparatus used for the thermal insulation determinations (Plate 1). This consists essentially of two parts: the heat source and the receiver. The heat source, a cylindrical vessel with a three inch copper core in the bottom (center), contains a liquid maintained at a constant temperature. The receiver is a cylindrical base six inches in diameter with a center block of copper one and three-quarter inches in diameter and surrounded with insulating materials. The temperature difference is measured by a thermocouple with junctions embedded in the upper and lower copper blocks.

The heat source may be raised and lowered mechanically. A dial micrometer is placed so that the spindle of the micrometer rests on the top rim of the vessel and records the distance of movement. This dial records to 0.001 inches.

The vessel liquid is heated by an immersion heater with a

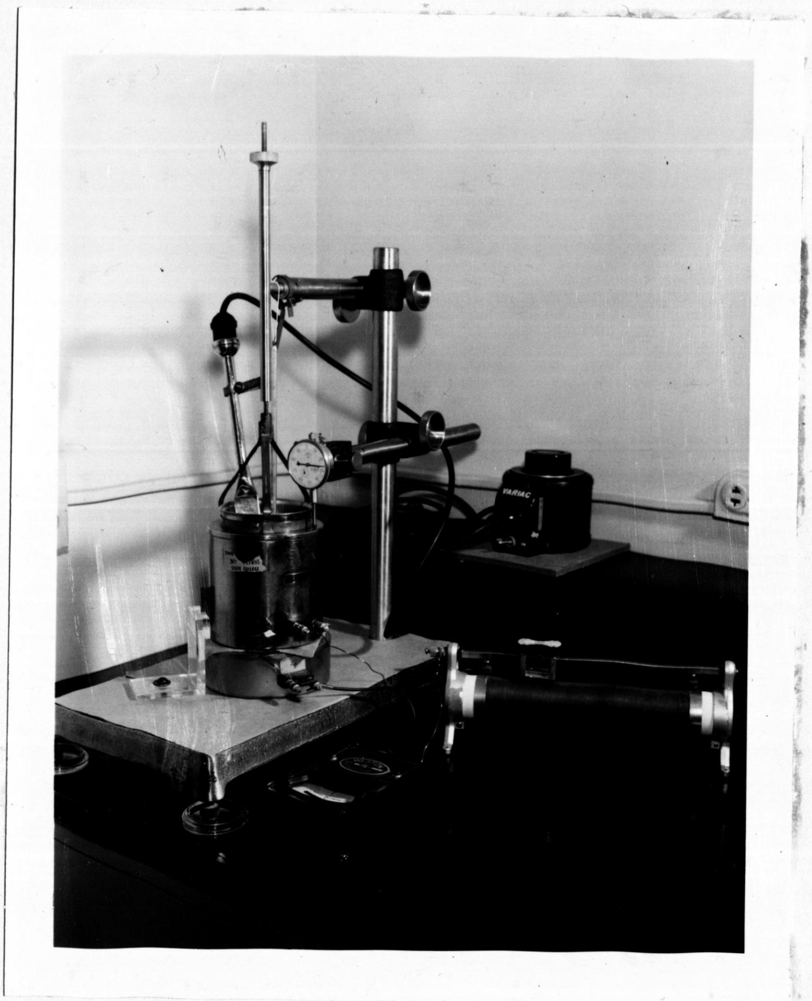


Plate 1. Modified Fitch thermal conductivity apparatus

variable transformer. To enable checking of the temperature at the center of the liquid a thermometer is suspended from the arm supporting the vessel mechanism.

The base which supports the heat source is insulated with heavy paper. The paper also serves to accurately place the receiver when the position of the receiver is marked before commencing measurements.

The receivers were checked with a level placed on the copper block and masking tape was applied to the bottom of the receiver when needed for leveling. The base which supported the apparatus was leveled with leveling screws.

Constantan junction binding posts on the heat vessel and the receiver were connected with constantan wire. Copper binding posts on the source vessel and receiver were connected with copper wire to terminals of a galvanometer in series with a slide rheostat.

Method of Measurement

For measurements of thermal insulation the mineral oil in the source vessel was maintained at 100°C. ± 2°C. by means of an immersion heater. The temperature of the receiver was that of the conditioning laboratory at the beginning of the measurement. The apparatus was arranged so that the heat vessel could be lowered to apply the same pressure as was used when measuring the fabric thickness with the compressometer. The compressometer equipped with a one-inch presser foot, was used to measure the thickness of fabrics and was read using a pressure of 0.10 pounds per square inch. After the sample was measured to determine thickness it was laid on a receiver, face side up, taped in

position and placed under the heat source. By means of the dial of the micrometer the vessel was then lowered to the measured thickness of the fabric. The galvanometer needle was adjusted with a rheostat to be slightly to the right of 30. When the needle dropped to exactly 30 a stop-watch was started and the galvanometer readings were recorded at two minute intervals.

Eight galvanometer readings were recorded for each three samples of all fabrics and combinations of fabrics. The values for the three replicates were averaged and the results were used to calculate the coefficient of thermal conductivity. The first five readings were plotted on semi-logarithmic graph paper using the galvanometer readings as the abscissa and the time in minutes as the ordinates. A straight line was drawn through these points using the line that best fitted the plotted points. The last three readings were not used as the line tended to become curvilinear instead of linear.

Three different receivers were used with the apparatus. After each measurement, to facilitiate cooling, a beaker of ice was placed on the receiver for a short time then the receiver was allowed to regain the temperature of the standard atmosphere of the laboratory.

Thermal insulation was also measured with a thermal box, (Plate 2), a type of apparatus with an aperture simulating a window on the vertical side of a wooden box. This 23 x 23 x 23 inch box was separated from its foil lined 18 x 18 x 18 inch inner cardboard box with a granular type insulating material. A thermostat automatically maintained a 97°F. temperature within the box by controlling the heat source, a 100

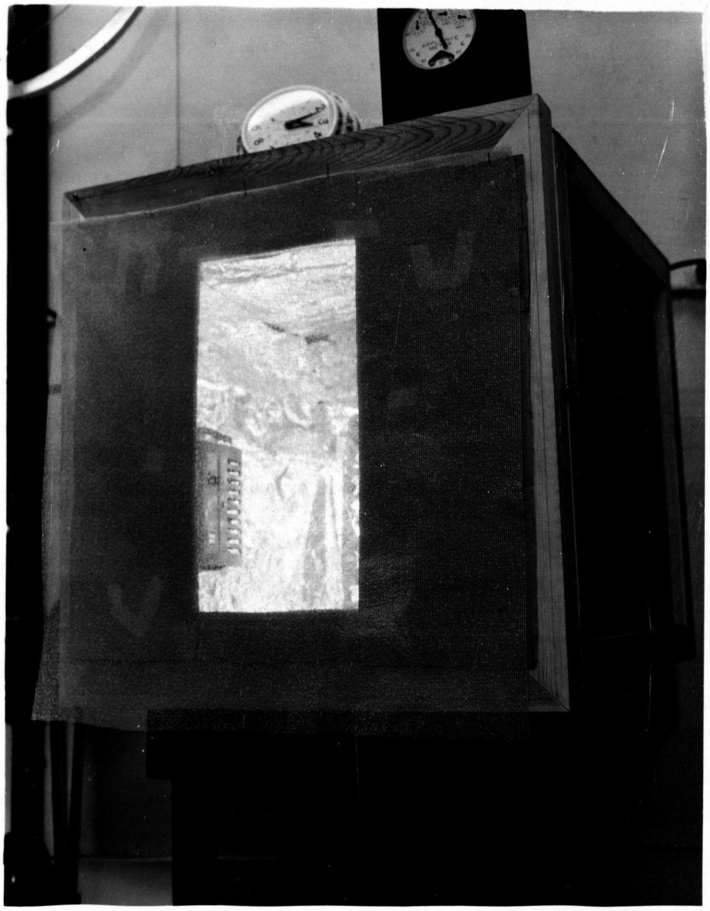


Plate 2. Thermal box

watt bulb.

Muslin fabric 20 x 20 inches was fastened over the 8 x 16 inch opening while the box was pre-heated and brought to equilibrium. Samples were secured for heat measuring with the warp in the vertical direction. An appliance watt-meter was connected and the starting time noted. The watts were recorded for one hour. The average of the watts recorded for two samples was reported for each fabric as the watts per hour.

Statistical Evaluation

The data collected in this study have been subjected to statistical analysis by the use of variance and covariance analysis (23) (49). Analyses of variance were used to determine differences among the fabrics, the fabric groups and lined fabrics for thermal insulation and loss in breaking strength due to degradation by heat and light.

The thermal insulation values for the lined fabrics were compared with the sum of the values for the single fabrics involved by analysis of variance. Variances and "F" values were determined in order to note the significance of the source of variation and, in order to make more precise comparisons between the two methods of measurement.

The linear relationship between loss in breaking strength and the number of hours in the Fade-Ometer were shown by coefficients of linear regression, coefficients of correlation and heterogeneity of regression.

The formulas used for statistical evaluation are as follows:

$$\bar{X} = \frac{\Sigma X}{N}$$

$$F = \frac{\text{MS effect}}{\text{MS error}}$$

$$b_{yx} = \frac{\Sigma xy}{\Sigma x^2}$$

$$r = \frac{xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$$

where

ΣX is the summation of the number of items

$\bar{X}$ is the mean

N is the number of items

F is the ratio of the mean square variances being tested for significance

MS is the mean square

b_{xy} is the coefficient of linear regression of y on x

Y is the dependent variable

X is the independent variable

x is the deviation from the mean in x

y is the deviation from the mean in y

r is the coefficient of correlation

DATA AND DISCUSSION

Discussion of the data collected in this study of thermal insulation and degradation of single and lined drapery fabrics is divided into four sections. In the first section data for the construction of the fabrics and of the yarns used in them are given. This information was compiled so that the fabrics could be accurately described and any relations among these properties and thermal insulation or degradation elucidated. Data for thermal insulation of each of the fabrics and combination of fabrics are included in the second part. Next the differences found between the sum of the values for thermal insulation of the single fabrics and combinations of fabrics and linings are compared. Also the relationship found between thermal insulation and the other physical properties for the single and lined drapery fabrics are discussed. Finally the data gathered for the residual strength and color fastness of the fabrics singly and lined after specific exposures to the carbon arc is presented. The interrelationship found between the fabric degradation and physical properties is discussed. All statements as to the significance of differences among single fabrics and lined fabrics have been substantiated by analysis of variance and covariance.

Many of the comparisons made in the study are based on six groupings of fifteen fabrics. Hereafter these groups are referred to in an abbreviated form in the text, tables and illustrative figures. The designations are as follows:

CT Textured cotton with an uneven surface.

CD Drip-dry cotton with a smooth, closely woven surface.

CC	Chintz, cotton with a smooth, glossy, closely woven surface.
GO	Patterned, opaque glass fiber.
GM	Marquisette, open weave glass fiber.
LC	Lining, Chintz.
LM	Lining, Milium-sateen with aluminum coating.
LU	Lining, Unbleached muslin.
LS	Lining, Sateen.

Experimental Materials

Drapery Fabrics

The drapery fabrics used in this investigation include the textured cottons in which the highest priced fabric had the firmest damask weave while the other two had variations of plain weave.

The drip-dry fabrics were both satin weaves, however, the higher priced fabric was a filling faced 5 shaft satin which appears smoother, lighter and had more sheen than the warp faced 5 shaft satin.

The two chintz fabrics both had plain weaves and were smooth, glazed and similar in appearance.

Both the opaque glass fiber draperies had identical plain weaves with warp floats forming a small geometric pattern. The fabrics had a definite sheen.

Because of the novelty yarns of loop and boucle in the glass fiber marquisette draperies they did not have a sheen. They were both leno weaves. The lowest priced drapery had a more open effect with a loop yarn in the filling while the higher priced drapery had a loop and

boucle in the fill in a two and two sequence.

Lining Fabrics

The two plain weave linings were the least expensive of the four. The chintz had a smooth, glazed appearance while the unbleached muslin was rough and dull.

The two 5 shaft satin weave linings were filling faced. The higher priced lining was coated on the back surface with aluminum.

Descriptive Characteristics of Experimental Materials

Data which describe the fabrics included in this study are given in Tables 1, 2, 3 and 4. Count, weight, thickness and yarn number are given in Table 4. The fabrics were divided into groups as previously mentioned; i.e. textured cottons, drip-dry cottons, chintzes, opaque glass fiber, marquisette glass fibers and linings.

Fabric Count

All cotton fabrics had a greater number of yarns per inch in the warp direction than the glass fiber fabrics. In number of yarns per inch, the cotton fabrics ranged from approximately 66 to 123 warpwise and 26 to 150 fillingwise while the glass fiber fabrics ranged from 26 to 58 warpwise and 17 to 53 fillingwise. The balance between the number of yarns per square inch was better in the glass fiber fabrics than in the cotton fabrics where only the chintzes and the unbleached muslin had nearly balanced yarns warp and fillingwise. The textured cottons all had less than half the number of fillingwise yarns per inch than

Table 3. Fiber Content, Weave Structure, and Surface Character of Experimental Materials

Fabric designation		Fiber content	Weave	Character of fabric surface
Textured drapery	1	Cotton 100%	Plain, variation	Uneven
Textured drapery	2	Cotton 100%	Plain, variation	Rough, bark cloth
Textured drapery	3	Cotton 100%	Damask, satin variation	Patterned, uneven, firm
Drip-dry	1	Cotton 100%	Warped faced satin 5 shaft	Smooth
Drip-dry	2	Cotton 100%	Filling faced satin 5 shaft	Smooth, sheen
Chintz	1	Cotton 100%	Plain weave	Smooth, gloss
Chintz	2	Cotton 100%	Plain weave	Smooth, gloss
Pattern drapery	1	Glass fiber 100%	Plain with small geometric pattern-float (2) warp	Uneven, sheen, opaque
Pattern drapery	2	Glass fiber 100%	Plain with small geometric pattern-float (2) warp	Uneven, sheen, opaque
Marquisette	1	Glass fiber 100%	Leno, loop filling yarn	Open, rough
Marquisette	2	Glass fiber 100%	Leno, loop and boucle filling yarns (2 and 2)	Open, rough, closer weave than 1
Chintz lining		Cotton 100%	Plain	Smooth, gloss
Milium lining		Cotton with aluminum coating	Filling faced satin 5 shaft	Slight sheen to cotton, metal back slight sheen
Unbleached muslin lining		Cotton 100%	Plain	Slightly rough
Sateen lining		Cotton 100%	Filling faced satin 5 shaft	Slight sheen

Table 4. Descriptive Properties of Fabrics and Yarns of Experimental Fabrics

Fabric designation	Fabric count yarns per inch		Fabric weight wt. per sq. yd.	Fabric thickness	Yarn No. Tex (gms. per 1000 m)	
	Warp	Filling	Ounces	Inches	Warp	Filling
Draperies						
CT 1	87.0	37.0	6.4831	.028	38.8	58.7
CT 2	70.3	26.0	8.4354	.034	51.3	120.4
CT 3	107.0	33.7	8.2068	.028	32.8	96.4
CD 1	122.7	60.7	5.7013	.011	27.7	21.6
CD 2	96.7	150.0	4.2291	.009	14.2	14.8
CC 1	89.7	76.0	3.5387	.008	18.1	15.8
CC 2	85.0	74.3	3.1227	.007	18.6	15.1
GO 1	57.7	53.3	4.3846	.010	32.8	33.5
GO 2	56.7	52.3	4.3983	.010	33.8	33.0
GM 1	26.0	17.0	4.6589	.018	67.7	125.6
GM 2	36.0	18.0	4.5811	.021	35.1	148.5 boucle 128.7 loop
Linings						
LM	66.0	102.7	3.5022	.009		
LU	78.0	77.0	3.6485	.013		
LS	64.7	101.0	3.3421	.009		
LC	89.0	74.7	3.5570	.008		

warpwise.

The five fabrics with satin weaves; that is, CT 3, CD 1, CD 2, LM and LS, have long float yarns which impart a better draping quality to the material. The float yarns are either warp or fillingwise giving the direction of the floats a higher count.

As can be seen in Table 4 three of the 15 fabrics had appreciably more yarns per inch fillingwise than warpwise. These were the three cotton fabrics with filling faced satin weaves; namely, CD 2, LM and LS.

The two marquisette glass fiber fabrics had the least number of yarns per square inch while the cotton drip-dry fabrics had the most. The yarns per square inch were 43 and 54 for glass marquisette whereas the drip-dry fabrics were 246 and 182. The type of weave accounts for the number of yarns per square inch.

<u>Fabric Weight</u>

The textured cotton fabrics were the heaviest fabrics with CT 1 being the lightest of this group and CT 2 the heaviest. Fourth heaviest of all the fabrics was CD 1 followed by the glass fiber groups in the following sequence: GM 1, GM 2; and GO 2, and GO 1.

The lightest of the fabrics was the CC 2 followed by the cotton sateen lining.

<u>Fabric Thickness</u>

The greatest thicknesses among all fabrics were recorded for the textured cottons of which CT 2 was the thickest. The fourth thickest

fabric was GM 2 followed by GM 1.

The thinnest fabric was CC 2 followed by CC 1.

A definite correlation was noted between thickness and weight where CT 2, the heaviest fabric, was also the thickest. The same relationship existed with CC 2 which is the thinnest fabric and also the lightest. Although CD 1 was the fourth heaviest it was only the seventh greatest in thickness probably due to the finer yarns. Next in direct relationship to thickness and weight is the GM group.

Yarn Number

For the comparison of the size of yarns the yarn number was converted to Tex units.

The filling yarns were equal to or greater in size than the warp yarns in all fabrics except CD 1, CC 1, CC 2 and GO 2. The glass fiber marquisette 2 had the greatest contrast between warp and filling yarn numbers. A marked difference was also noted between the size of yarns in the two directions of the CT 2 fabric.

The yarns most nearly the same size warp and fillingwise were those most nearly balanced in yarn count in the two directions. The CD 2 had the smallest size in both directions while the GM 1 had the largest warp size and GM 2 the largest filling yarns.

Within the groups the glass marquisettes and the textured cottons had the largest contrast in yarn sizes and also had the largest yarns both warp and fillingwise; conversely the chintzes had the smallest and most nearly similar yarn size in both directions.

Thermal Properties

The means for individual fabrics and fabric groups are given in Tables 5 and 6 and the analysis of variance for thermal conductivity appear in Appendix Tables 1 and 2.

The thermal property of a fabric is its ability to resist or permit the passage of heat, according to Skinkle (48). Intimately associated with thermal properties are porosity and permeability, since the warmth of a fabric is due to the dead air space and not actually to the fiber itself.

Thermal Conductivity-Plate Method

An analysis of the thermal insulating values indicated significant differences between drapery fabric classes. A highly significant difference was found between the glass fiber and the cotton fabric classes. As a group, the glass fiber fabrics had thermal insulation values which show the least calories per unit thickness (Table 5).

The GM 1 and GM 2 fabrics had the lowest yarn counts per square inch (Table 4) and an open marquisette weave, both of which contributed to dead air space within the fabric. This air was trapped between the receiver and the heat source and therefore was not subject to convection currents hence not in motion. Skinkle (48) says the thermal properties of a fabric are, as a rule, dependent upon the amount of air space as well as the size of the spaces since, in general, the solid fibers themselves are not good insulators. However, air spaces trapped by the fibers may be very efficient insulators, if the air is not in motion.

Table 5. Means for Thermal Conductivity of Drapery Fabrics with and without Linings Measured by Plate Method

Drapery	Lining	Thermal insulation unit thickness $\frac{°C\ Sec.\ m^2}{Cal.\ cm.}$	Compressibility 0.10 lbs./in.^{2} pressure lbs./cm.^{2}
CT 1	None	.000182	.0838
CT 1	LM	.000159	.1067
CT 1	LU	.000170	.1168
CT 1	LS	.000170	.1092
CT 2	None	.000156	.1110
CT 2	LM	.000170	.1321
CT 2	LU	.000147	.1397
CT 2	LS	.000186	.1346
CT 3	None	.000174	.0813
CT 3	LM	.000163	.1041
CT 3	LU	.000199	.1118
CT 3	LS	.000178	.1143
CD 1	None	.000207	.0483
CD 2	None	.000217	.0254
CC 1	None	.000193	.0254
CC 1	LC	.000135	.0584
CC 1	LS	.000126	.0635
CC 2	None	.000205	.0254
CC 2	LC	.000121	.0533
CC 2	LS	.000129	.0610
GO 1	None	.000122	.0330
GO 2	None	.000079	.0330
GM 1	None	.000113	.0635
GM 2	None	.000108	.0787
None	LC	.000182	.0179
None	LM	.000136	.0279
None	LU	.000114	.0406
None	LS	.000104	.0305

Although glass fiber has a much greater density than cotton fiber, because of the yarn structure and the fabric weave the glass fiber fabrics had more space for dead air and no convection currents to move it.

The other glass fiber fabrics, GO 1 and GO 2, had the next to the lowest yarn count per square inch. The yarn size was smaller than half of the other fabrics and the weave was plain. All these factors provided dead air spaces. The absence of convection currents, as previously mentioned, was also applicable here.

Among the lining fabrics which were combined with the textured cotton and chintz fabrics no significant differences were found. However all of the linings in various combinations with the drapery fabrics in some instances produced better insulation values than the fabrics alone (Figure I).

The least expensive textured cotton, CT 1, had better insulation value when combined with any one of the linings than when used alone. Of the three linings, milium combined with CT 1 and CT 3 gave the best insulation values and was also better insulators than the drapery fabric alone. Since the draperies lined with milium were the thinnest of the three lining-drapery combinations, no correlation can be assumed between the insulative value and the thickness.

The unbleached muslin lining combined with CT 1 and CT 2 had better insulation values than the drapery fabric alone. This lining-drapery combination was also the thickest of the three lining-drapery pairs.

The chintz and sateen lined chintzes had far better insulation

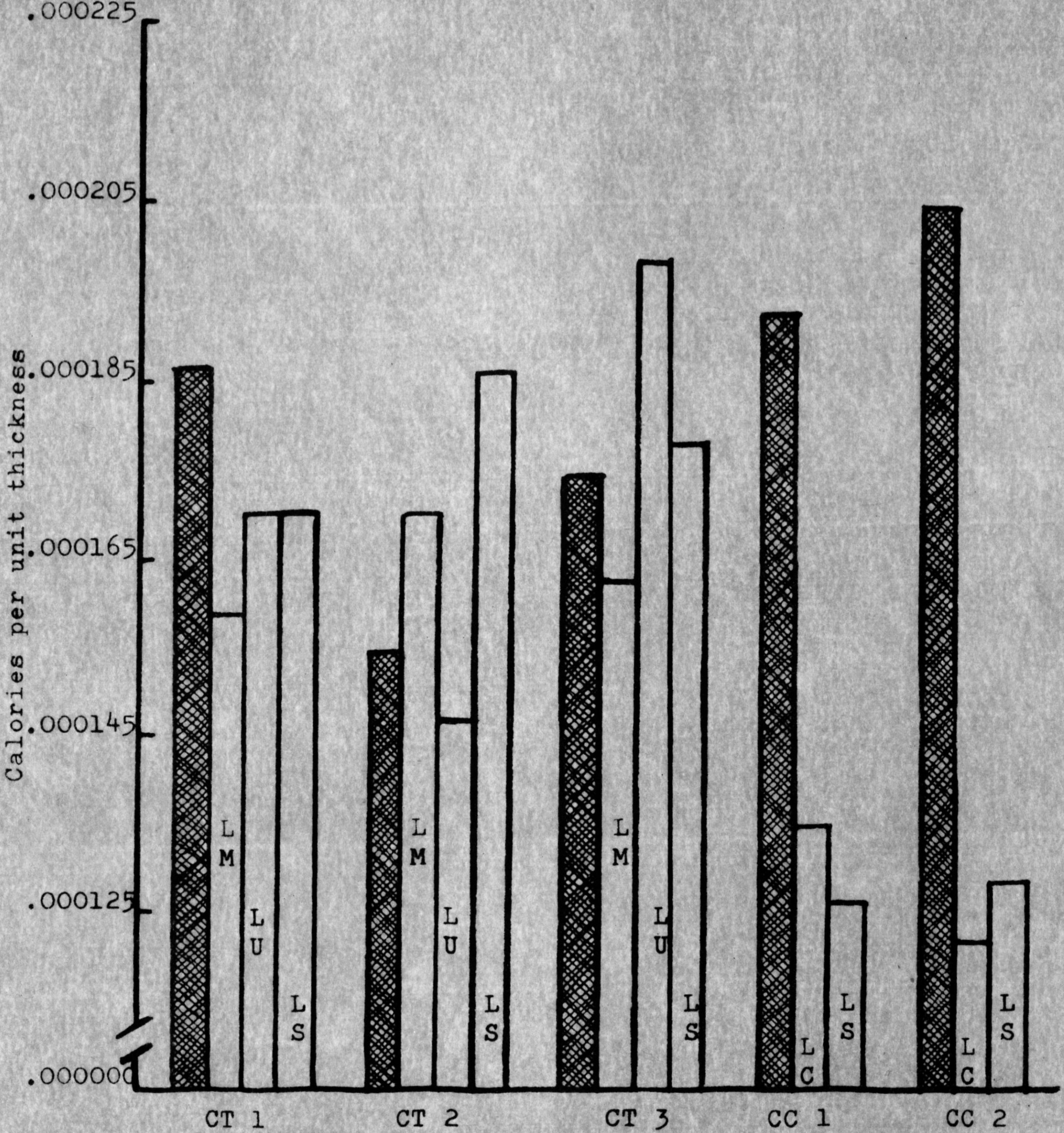
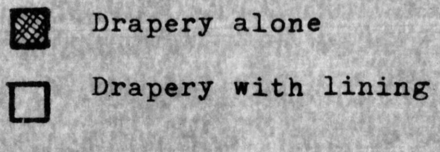


Figure I. Thermal insulation values of draperies alone and with various linings--measured with plate method



values than the unlined chintz fabrics. In this instance also, the thickness was considerably increased with the addition of the lining.

The sateen was an effective insulator with the chintzes but with the textured cottons 2 and 3 it lessened the insulation value.

From these observations a correlation is in evidence between thickness and insulation value as related to the plate method of measuring thermal conductivity.

Thermal Conductivity-Thermal Box

Drapery fabrics when hung are subjected to convection currents. The plate method, with findings just noted, does not have such currents. Therefore, the thermal box with a side aperture was also used to measure the thermal properties of the fabrics in watts per hour.

Fabric classes were found to have no significant differences in insulative value nor were any differences found between the glass fiber fabrics as a group and the cotton fabrics.

The glass fiber marquisettes, GM 1 and GM 2, used approximately twice the number of watts per hour as did any of the other drapery fabrics lined or unlined (Table 6). This was a highly significant difference. Although the insulation of a fabric is due to the dead air spaces, when these spaces are too large they are more readily affected by convection currents. This was the situation relevant to the GM fabrics. As previously mentioned, they had the most open weave and the lowest yarn counts per square inch of all the fabrics. The air spaces were so large that only when the air was trapped as it was between the metal plates did it have a high insulative value. This fabric when exposed

Table 6. Means for Thermal Conductivity of Drapery Fabrics with and without Linings Measured by Thermal Box

Drapery	Lining	Watts Per hour	Thickness 1 lbs. pressure/in.^{2} Lbs./in.^{2}
CT 1	None	31.0	.028
CT 1	LM	28.0	.032
CT 1	LU	29.5	.038
CT 1	LS	32.5	.035
CT 2	None	27.5	.034
CT 2	LM	28.0	.044
CT 2	LU	25.5	.045
CT 2	LS	31.0	.043
CT 3	None	27.5	.027
CT 3	LM	29.5	.036
CT 3	LU	27.0	.036
CT 3	LS	33.0	.035
CD 1	None	29.0	.016
CD 2	None	38.0	.010
CC 1	None	31.5	.008
CC 1	LC	27.0	.015
CC 1	LS	31.0	.020
CC 2	None	34.5	.008
CC 2	LC	31.0	.013
CC 2	LS	30.5	.019
GO 1	None	31.0	.010
GO 2	None	29.0	.010
GM 1	None	70.0	.018
GM 2	None	60.5	.020
None	LC	33.5	.008
None	LM	26.5	.008
None	LU	31.0	.013
None	LS	32.5	.010

to convection currents quickly lost the warmed air accounting for its low insulative value when hung on the heat box.

The thermal insulation value among linings as combined with drapery fabrics varied somewhat. The sateen lining required more watts per hour to maintain a constant temperature than did the fabric alone or other linings with cotton textured fabrics. Among linings the cotton sateen had similar thickness and total yarn count per square inch but was the lightest weight lining with a considerable imbalance in warp and filling yarn count. This situation could vary with the grades of sateen, this being a medium grade.

The unbleached muslin lined draperies showed the best insulation values among linings used with two of the textured cottons (Figure II). The insulative value of all three muslin-textured cotton combinations were better than the drapery fabrics alone. A correlation exists between thickness and insulative value where all muslin lined draperies were the thickest of all lining combinations. These findings substantiate the thickness, insulative value correlation noted with the plate method.

The chintz fabrics were both better insulators when lined with chintz or sateen although the difference wasn't as marked with the heat box as the plate method. Here again, the addition of lining to fabric produced a much greater thickness and an interrelationship between insulative value and thickness was noted.

From this data, it appears that linings afforded better insulative values for textured cottons, and even more for chintz fabrics. For more effective insulation it would be well to line chintz fabrics with chintz

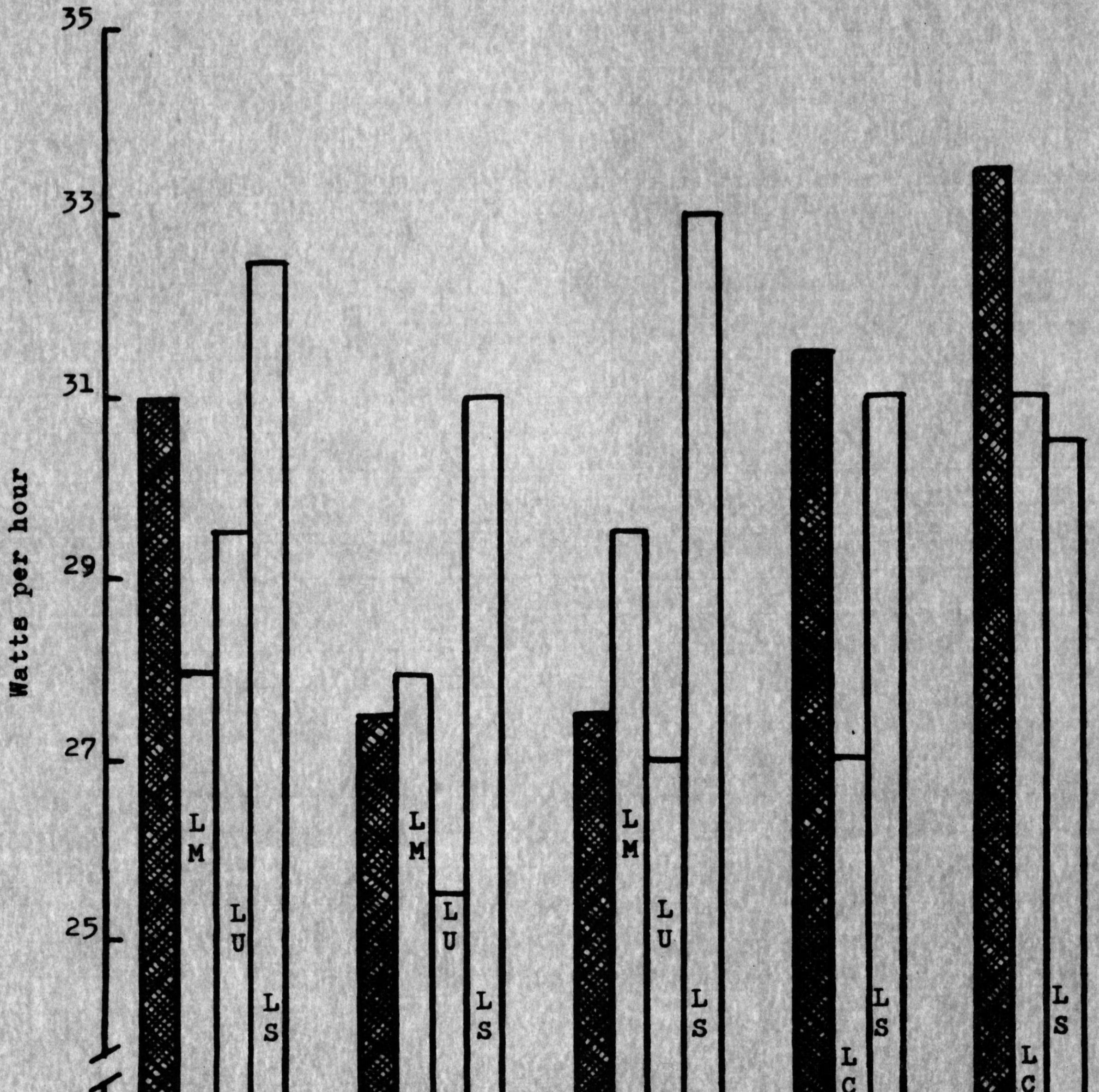
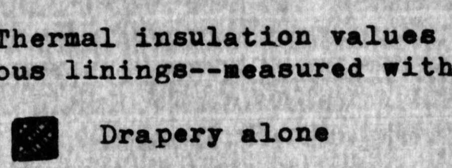


Figure II. Thermal insulation values of draperies alone and with various linings--measured with thermal box



or sateen and line textured cotton fabrics with a heavier, thicker lining material such as the grade of unbleached muslin used in this study.

Durability Properties

The properties studied which relate to the durability of the fabric were breaking strength and elongation. These were studied before and after specified hours of exposure in the Fade-Ometer. The means for individual fabrics and combinations of fabrics are given in Tables 7 and 8 and the analyses of variance and covariance for these properties are in Appendix Tables 3 and 4.

Breaking Strength

The strength of a fabric as measured in the laboratory before and after treatment is considered as an indication of the comparative quality of the materials.

This study concerned the strength loss as related to fabric degradation. However it should be noted that fabrics studied differed in their original strength; i.e. glass fiber marquisette, GM 2, had the least strength while cotton drip-dry, CD 1, and cotton textured, CT 3, had the most.

The more expensive fabrics in each of the cotton drapery groups showed the least loss in strength after 200 hours exposure in the Fade-Ometer (Table 7, Figure IIIa, IIIb, IV). The three textured cotton fabrics likewise followed this pattern with the least expensive fabric showing the greatest loss in strength.

Table 7. Means for Warp Strength and Elongation of Drapery Fabrics

Fabric alone	Breaking strength pounds				Breaking strength elongation percent			
	New	Exposure hours in Fade-Ometer			New	Exposure hours in Fade-Ometer		
		100	200	400		100	200	400
CT 1	78.2	63.5	54.0		14	10	10	
CT 2	90.7	76.7	68.8	55.2	12	9	8	7
CT 3	102.2	89.2	86.5	80.2	8	8	7	7
CD 1	107.5	96.0	93.2		8	7	7	
CD 2	46.8	49.5	45.3		5	5	4	
CC 1	46.7	41.0	38.8		7	7	5	
CC 2	49.7	49.5	49.2		7	7	7	5
GM 1	46.7	53.0	51.7	55.5	6	5	5	7
GM 2	28.5	28.2	32.0	30.5	5	6	5	5
GO 1	83.7	86.0	87.5	91.2	3	2	4	3
GO 2	81.2	94.0	84.3		3	3	4	
LC	47.2		39.2		7		7	
LM	29.3	26.0	19.7		7	5	5	
LU	49.2		35.2		13		11	
LS	28.8		27.5		5		5	

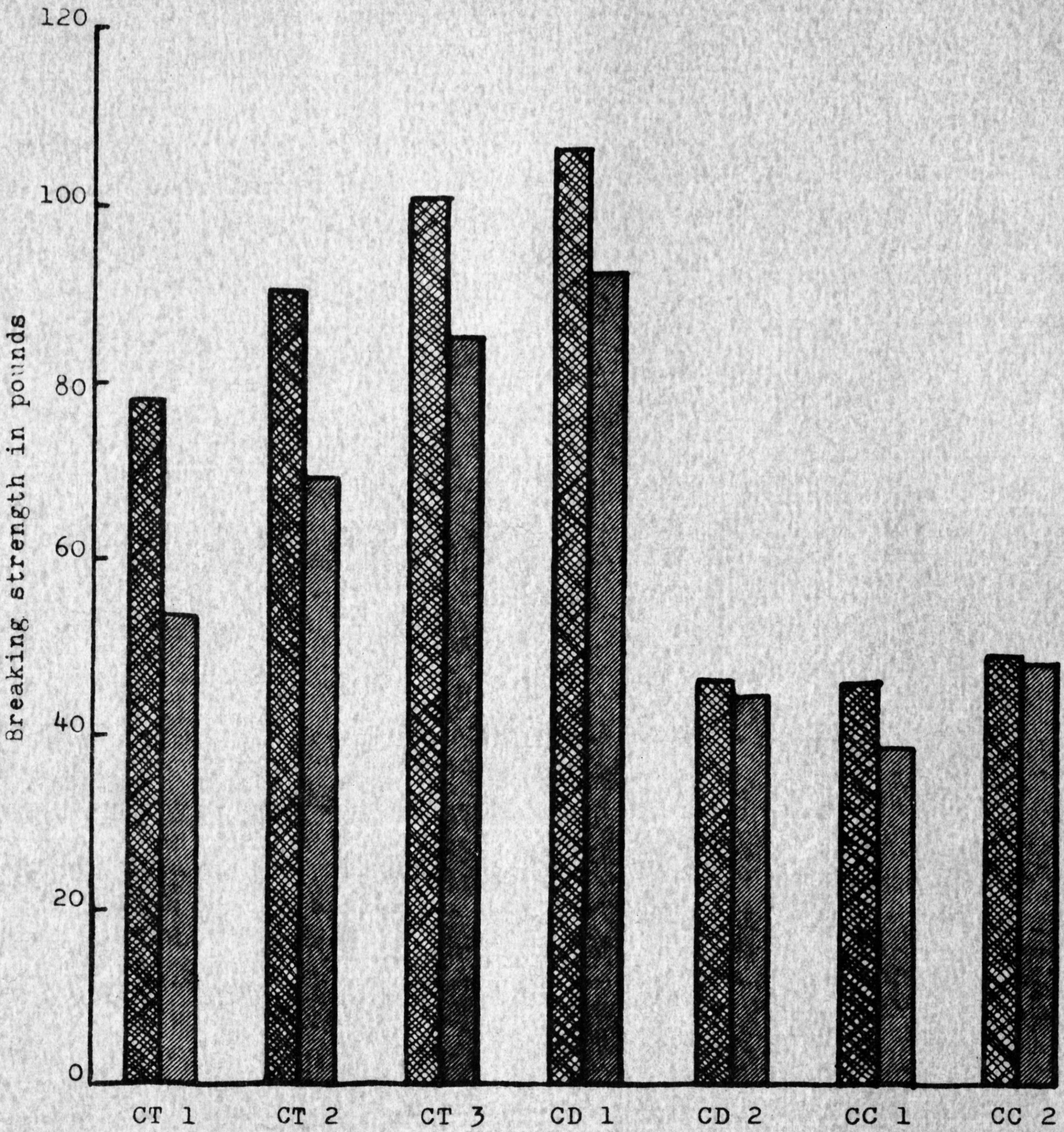
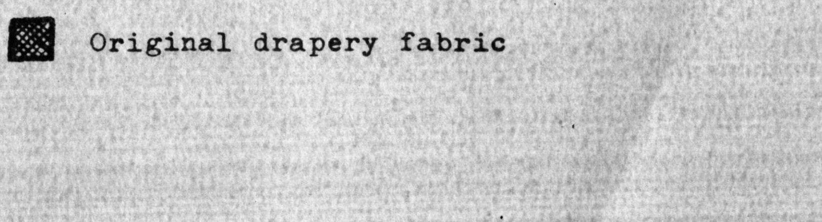


Figure III a. Effect of 200 hours exposure in the Fade-Ometer on the original strength of the fabric



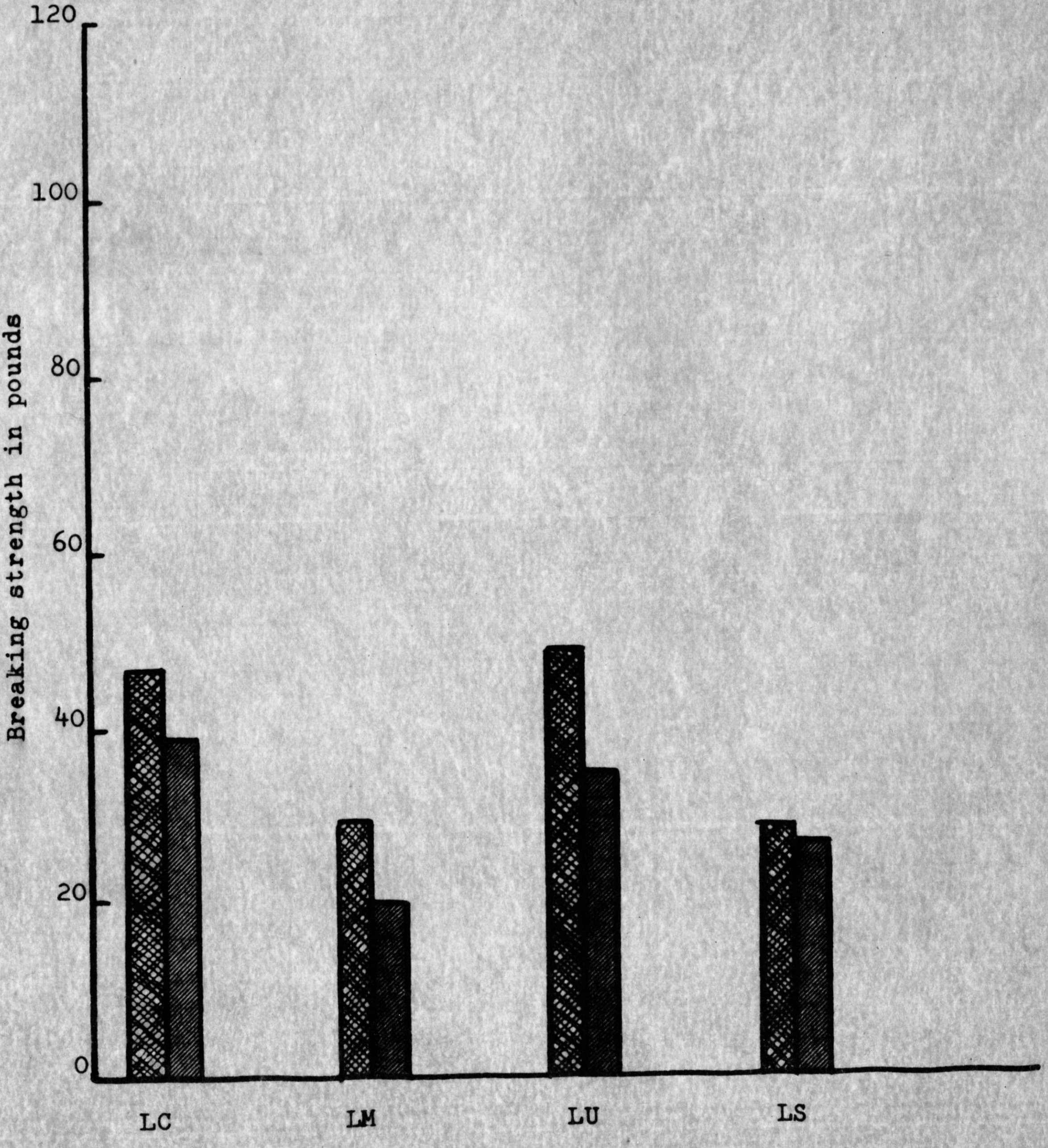


Figure III b. Effect of 200 hours exposure in the Fade-Ometer on the original strength of the fabric

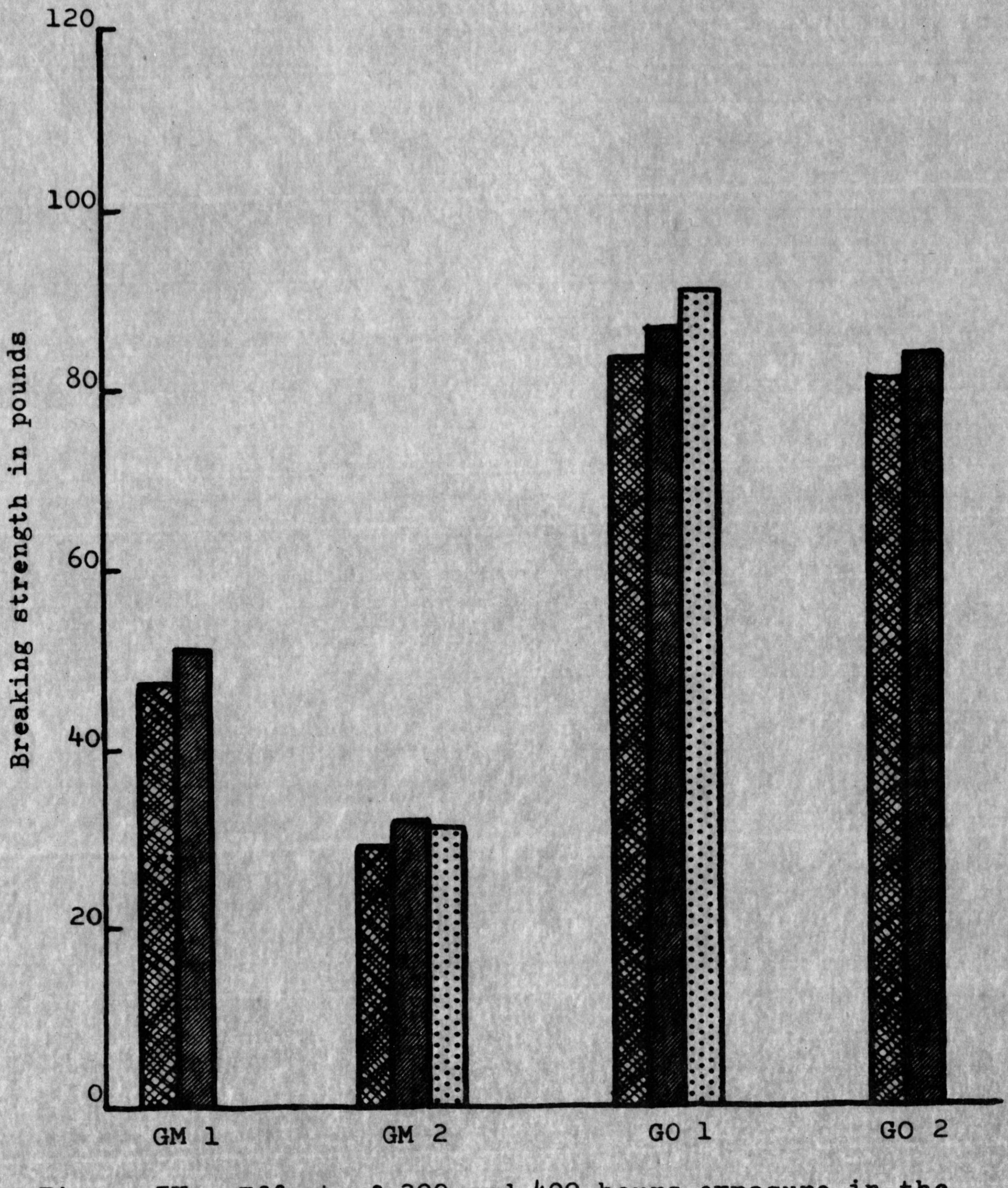


Figure IV. Effect of 200 and 400 hours exposure in the Fade-Ometer on the original strength of the fabric

Original drapery fabric

Drapery exposed 200 hours

Drapery exposed 400 hours

All glass fiber fabrics gained strength after 200 hours and GM 2 and GO 1 exposed for 400 hours remained above the original strength of the unexposed fabric.

The fabric groupings showed variations in strength after 200 hours of exposure and this was found highly significant (Appendix Table 3). The chintz group showed a very small loss in strength. Of the linings, although low in original strength, LM, LS and LC showed approximately the same amount of loss as the chintzes. The unbleached muslin had a slightly greater loss. However the best fabrics for strength retention were CC 2 with a half pound loss and LS and CD 2 with one and a half and a half pound respectively. The textured cottons had the greatest loss per fabric.

The glass fibers are known to be unaffected by heat and sunlight which accounts for their behaviour, while the cotton fibers are known to diminish in tensile strength.

The cotton fabrics which showed the least strength loss were predominantly of the satin weave. This surface covering, close weave tends to protect the yarns from light exposure. The two textured cotton fabrics with the greatest strength loss had the largest yarn sizes and the fewest yarns per square inch, allowing more complete exposure of the yarns to heat and light.

The addition of a lining, as would be expected, retards the loss in strength of the fabric. Some linings afford more protection than others as can be seen in Table 8 and Figures Va and Vb. This difference was found significant. The aluminum coated sateen (Milium) lining

Table 8. Means for Warp Strength and Elongation of Drapery Fabrics when Lined

Fabric with lining	Breaking strength pounds				Breaking strength elongation percent			
	New	Exposure hours in Fade-Ometer			New	Exposure hours in Fade-Ometer		
		100	200	400		100	200	400
CT 1 +	78.2		67.3		14		11	
LM	29.3		16.7		7		4	
CT 1 +	78.2		59.8		14		10	
LU	49.2		33.0		13		10	
CT 1 +	78.2		61.8		14		12	
LS	28.8		26.2		5		5	
CT 2 +	90.7	81.2	85.0	82.5	12	10	10	10
LM	29.3	22.5	17.0	15.0	7	5	3	3
CT 2 +	90.7		75.3		12		8	
LU	49.2		35.7		13		10	
CT 2 +	90.7	84.0	76.0	73.0	12	10	10	10
LS	28.8	28.0	25.7	16.5	5	5	5	3
CT 3 +	102.2	96.0	94.3	90.8	8	10	7	7
LM	29.3	23.8	18.5	14.8	7	6	5	3
CT 3 +	102.2		88.7		8		7	
LU	49.2		34.8		13		10	
CT 3 +	102.2	94.5	85.8	87.0	8	8	7	7
LS	28.8	28.2	27.2	18.5	5	5	5	3
CC 1 +	46.7		44.3		7		7	
LC	47.2		33.8		7		5	
CC 1 +	46.7		42.3		7		7	
LS	28.8		25.5		5		5	
CC 2 +	49.7		48.7		7		7	
LC	47.2		35.2		7		5	
CC 2 +	49.7		49.8		7		7	
LS	28.8		27.3		5		5	

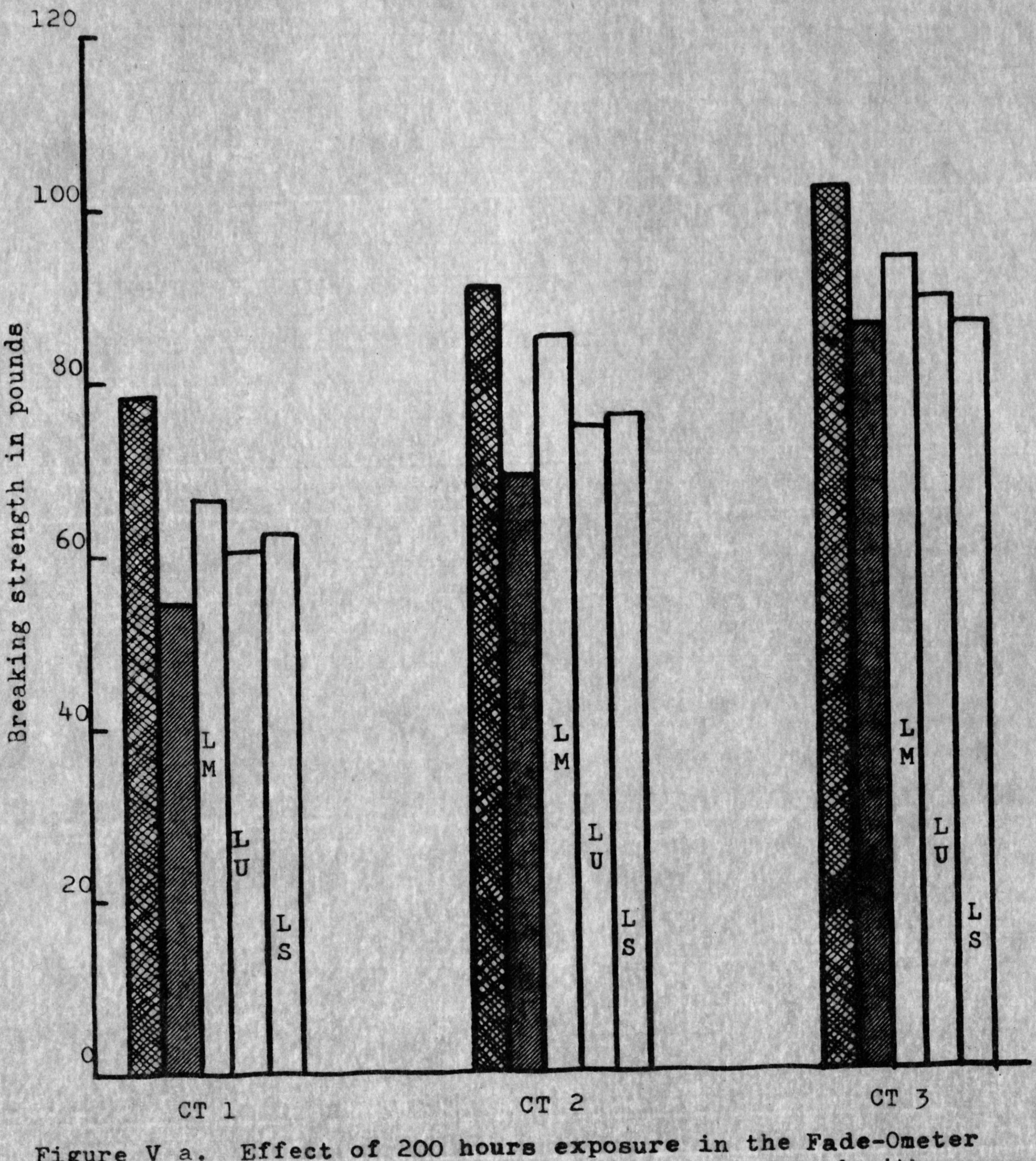
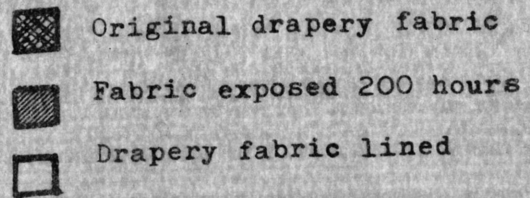


Figure V a. Effect of 200 hours exposure in the Fade-Ometer on the original strength of the fabric alone and with various linings



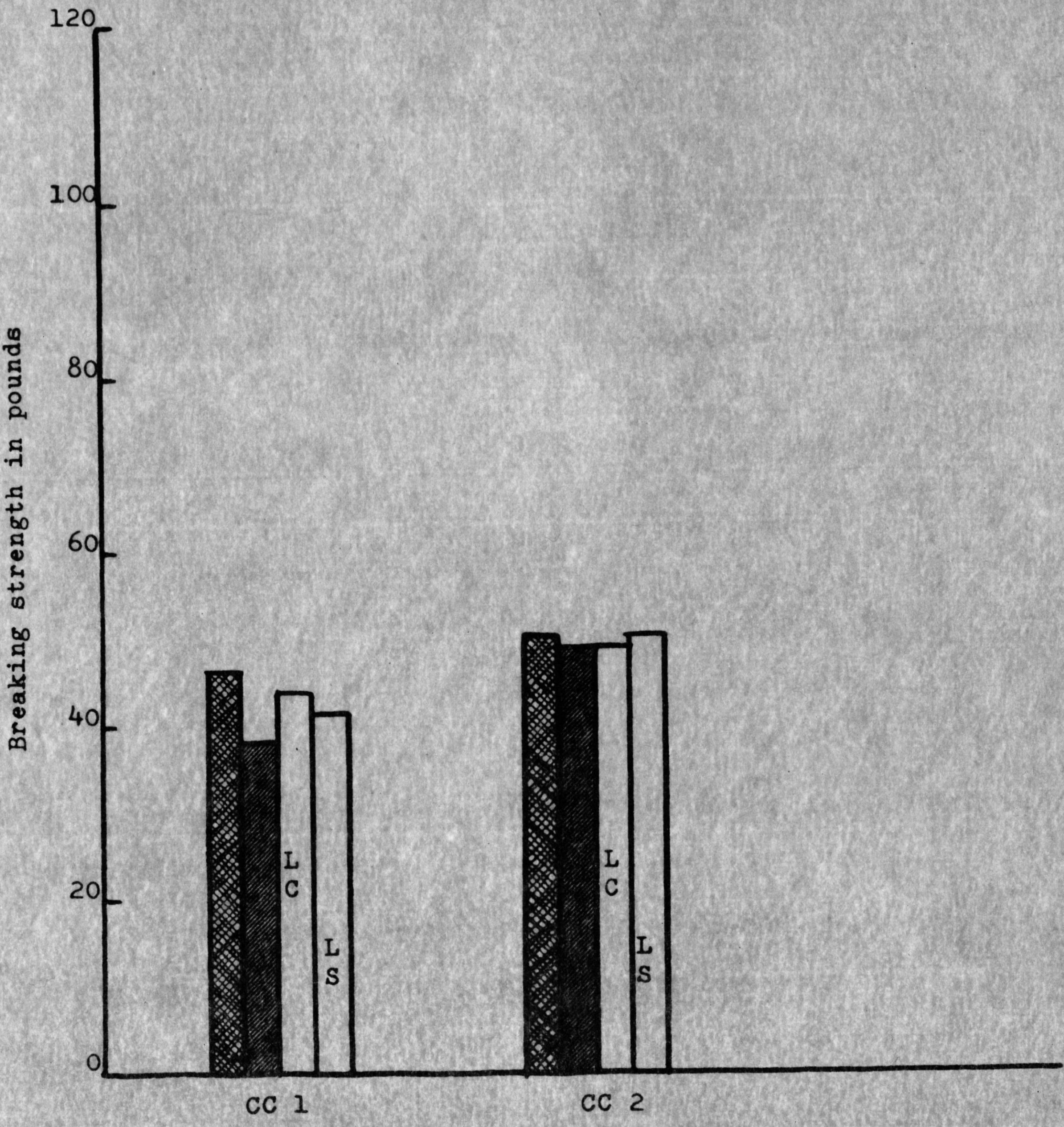


Figure V b. Effect of 200 hours exposure in the Fade-Ometer on the original strength of the fabric alone and with various linings

Original drapery fabric

Fabric exposed 200 hours

Drapery fabric lined

reduces the original strength loss of the single fabric to half for CT 3 and more than half for the textured cotton fabrics CT 1 and CT 2. The sateen lining was the next most effective for CT 1 and CT 2 but it did not show any change from the unlined for CT 3. The unbleached muslin was the least effective lining for CT 1 and 2 but it did improve the single fabric strength about one fourth.

The trend in loss of strength is shown in Appendix Table 4 and Figure VI for CT 2, CT 3, CC 2, GM 2, and GO 1 with exposures up to 400 hours. The Milium lined draperies tend to lose strength less rapidly than the sateen lined draperies. Both linings showed significant improvement in strength over the unlined fabrics.

The CT 2 fabric showed the highest correlation between hours of exposure and loss in breaking strength while CC 2 was the lowest of the three cotton fabrics exposed for 400 hours. For every hour of exposure the CC 2 was shown to have the least loss in strength while CT 2 presented the greatest.

The glass fiber fabrics had a positive correlation as would be expected with the GO 1 gaining the most strength.

Elongation

The elongation or stretch of the fabric is not especially important to drapery fabrics as draperies are not subjected to forces in normal use.

The fabric elongation was similar for all but glass fiber fabrics. Among the unexposed fabrics, CT 1 had the highest percent elongation. This is an inverse relationship to its breaking strength in which

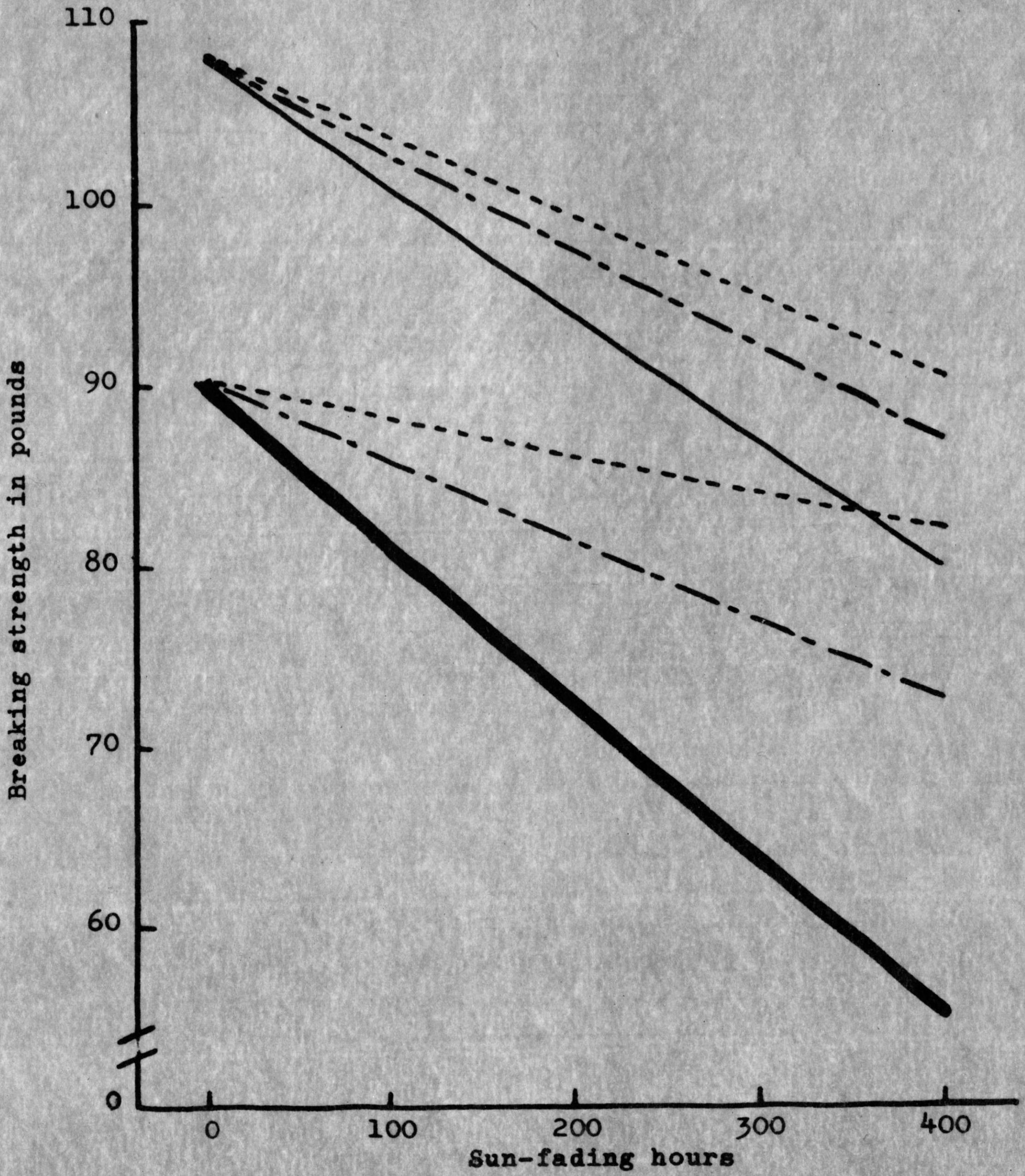
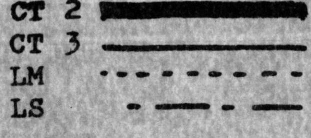


Figure VI. Loss in strength of two textured cotton drapery fabrics alone and with various linings after exposure in the Fade-Ometer 400 hours



it was lowest of all. This same inverse relationship is true of CT 2 which had the third highest percent elongation and next lowest breaking strength. The unbleached muslin lining was second in percent elongation.

All of the glass fiber fabrics and the sateen lining had the lowest percent elongation. After 200 hours of exposure to heat and light GO 1 and GO 2 increased their percent elongation while the rest of the fabrics had no gain or a slight loss in percent elongation as compared to the unexposed fabrics.

The lined draperies remained about the same or there was a small gain in percent elongation after 200 hours exposure.

Colorfastness

Colorfastness is an important factor in drapery fabric selection as draperies are an integral part of the rooms' interior design.

The means for colorfastness of the single and combined fabrics are given in Table 9. The glass fiber fabrics had no color loss after exposures up to 400 hours in the Fade-Ometer.

Evaluating the drapery fabrics without lining the CC 1 and CT 1 fabrics faded to a 1 rating on the Gray Scale in 100 hours of exposure, and CT 2 and CT 3 rated 1 when exposed for 400 hours.

When lined with Milium the original colors of the textured fabrics CT 1, CT 2 and CT 3 were retained (Figure VII). However with sateen and unbleached muslin, there was varying degrees of fading for these cotton textured fabrics, with sateen showing the better protection.

Table 9. Mean Values for Fabric Colorfastness as Measured by the Gray Scale*

Fabric	Colorfastness: Exposed hours in Fade-Ometer 100	200	400
CT 1	1	1	
CT 1 +		5	
LM		1	
CT 1 +		2	
LU		2	
CT 1 +		2	
LS		1	
CT 2	3	2	1
CT 2 +	5	5	5
LM	1	1	1
CT 2 +		3	
LU		1	
CT 2 +	4	4	3
LS	2	1	1
CT 3	4	4	1
CT 3 +	5	5	5
LM	1	1	1
CT 3 +		3	
LU		1	
CT 3 +	5	5	4
LS	2	1	1
CD 1	3	3	
CD 2	2	2	
CC 1	1	1	
CC 1 +		4	
LC		1	
CC 1 +		3	
LS		1	
CC 2	3	3	2
CC 2 +		4	
LC		1	
CC 2 +		4	
LS		1	
GM 1	5	5	5
GM 2	5	5	5

Table 9. Continued

Fabric	Colorfastness		
	Exposed hours in Fade-Ometer		
	100	200	400
GO 1	5	5	5
GO 2	5	5	
LC		1	
LM	1	1	
LU		1	
LS		1	

* Gradation from 5 = no color change

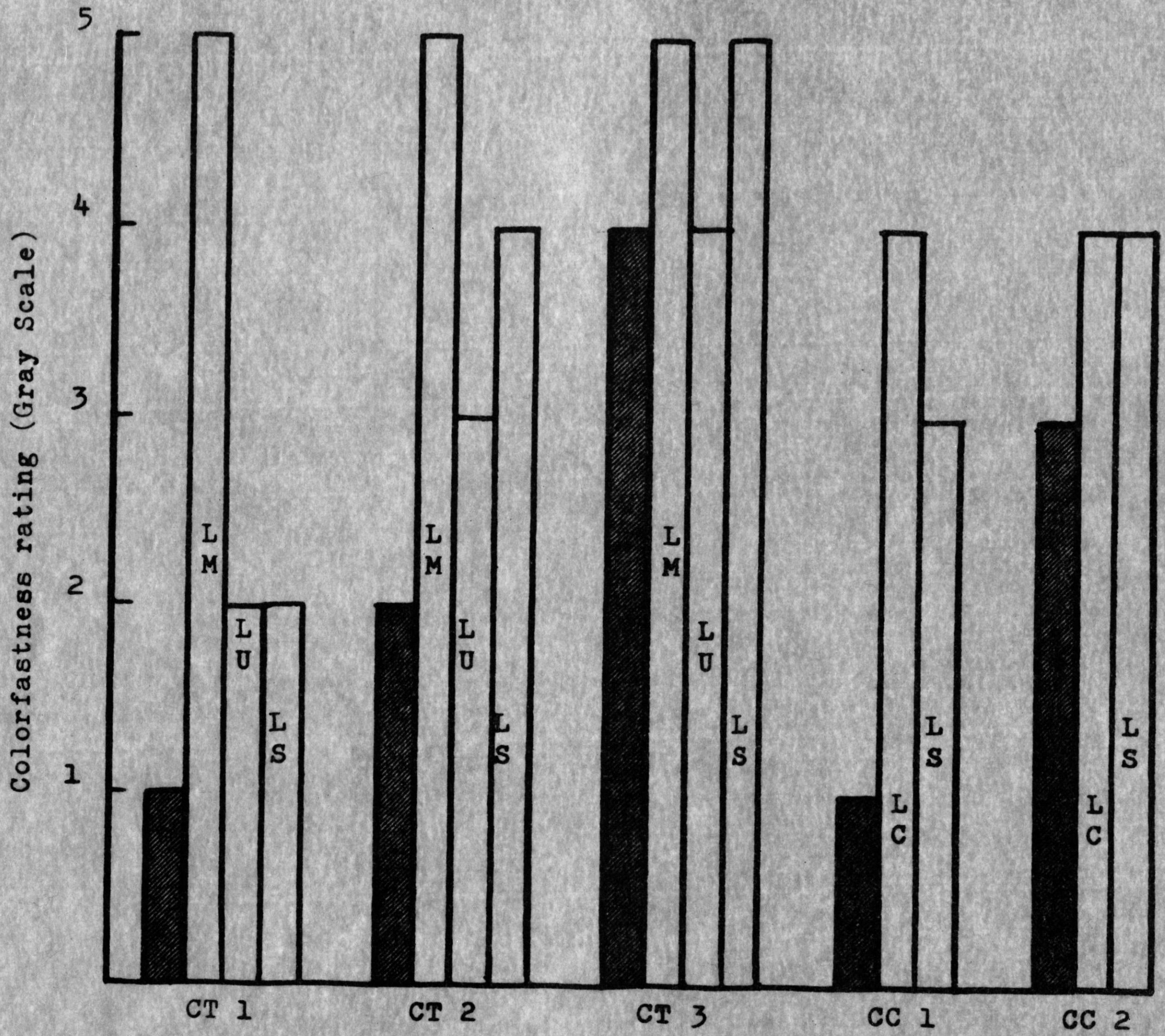
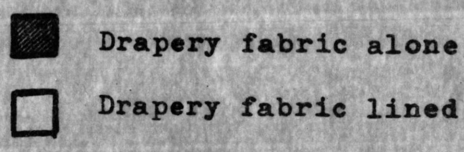


Figure VII. Colorfastness of drapery fabric alone and lined after exposure of 200 hours in the Fade-Ometer



The chintz, CC 2 faded to a 4 grade with linings LC and LS while CC 1 faded to a 3 rating with LS.

All linings faded to a 1 rating with 200 hours exposure.

SUMMARY

Fifteen cotton fiber, glass fiber and metal backed fabrics and combinations of these materials often found in draperies were included in this investigation. These drapery fabrics and linings varying in fiber, construction and price were studied with respect to certain properties which might be associated with thermal insulation and fabric degradation due to heat and sunlight.

The results produced by the two thermal conductivity measuring devices differed somewhat. This is to be expected as the one was a measure of calories per unit thickness and the other a measure of watts per hour with no relation to thickness. The presence of convection currents with the thermal box reversed the results for some fabrics. The glass fiber marquisette fabrics, GM 1 and GM 2, had next to the best insulating values with the plate method of measuring while with the thermal box exposed to convection currents, the GM fabrics had the lowest insulating values using approximately twice the watts used by any other lined or unlined fabric. The open marquisette weaves plus the lowest yarn counts per square inch resulted in spaces too open to trap air except when covered as in the plate method, hence the inverse results with the two measuring devices.

All fabrics measured in both instruments had better insulating values with one or more of the linings than alone. The textured cotton CT 2 lined with muslin when measured in both devices for thermal conductivity had the best insulative value of the textured cottons and had the greatest thickness recorded. This same thickness-insulative value

correlation was shown within the chintz groups measured by both devices where the pair with the best insulative value had the thickest combination of the group, namely: CC 2 with LS using the thermal box, and CC 1 with LS using the plate method.

The most effective linings within each of the textured cotton groups were: unbleached muslin with CT 2 and CT 3, Milium with CT 1 (box method); Milium with CT 1 and CT 3, and unbleached muslin with CT 2 (plate method). The sateen lined textured cotton fabrics all had lower insulation values than the drapery fabric alone (box method) and CT 2 and CT 3 had lower values lined than unlined when measured with the plate method. Sateen was the lightest weight lining whereas unbleached muslin was the heaviest. This suggests that weight of the lining fabric could be a factor in insulative value. Milium was the most effective lining with CT 1 when measured with the box and the plate method. Fabric CT 1 was the lightest weight textured cotton with the smallest size yarns. This would infer that the lining-drapery combination also depends upon the drapery fabric itself. While Milium may be more effective for added insulation with a lighter fabric a heavier lining is more effective with the heavier more dense drapery.

The light-weight thin chintz fabric has better insulation value with the addition of a lining such as chintz or sateen which are as thick or thicker than the chintz drapery.

Fabric cost and insulative value appear to have no direct relationship.

Breaking strength, elongation and colorfastness were measured to

determine fabric degradation. Glass fiber fabrics gained strength after 200 hours and GO 1 and GM 2 exposed for 400 hours remained above their original strength. The chintz fabrics had the least strength loss after 200 hours exposure. The linings had low original strength, and their strength loss was comparable to the chintz fabrics except for the unbleached muslin which had a greater loss. The cotton fabrics which showed the least strength loss were predominantly of the satin weave. The textured cotton fabrics had the greatest losses per fabric. The CT 1 and CT 2 with the greatest losses had the largest yarn sizes and fewest yarns per square inch allowing for more yarn exposure.

The addition of linings retarded the strength loss for all fabrics, however, more protection was realized from specific lining fabrics. Milium afforded the most protection for all of the textured cotton fabrics reducing the loss of strength of the single fabric to half for the CT 3, and more than half for CT 1 and CT 2. Sateen the next most effective lining for CT 2 and CT 1 did not change the single strength loss for CT 3. Muslin, although the least effective, did improve the single fabric strength loss about one-fourth for all three textured cotton fabrics.

The original colors were maintained for all of the textured cottons lined with Milium after exposures of 200 hours. Glass fiber fabrics retained their original color after 400 hours exposure.

Appearance as well as durability are two of the important features in the choice of draperies. The most expensive of the selections studied appeared to be the best fabrics to fulfill these criteria. The

most expensive of the textured cotton fabrics, CT 3, had the least loss in strength and least fading of the textured cottons after 200 hours exposure. The chintz, CC 2, had less strength loss and retained more of its original color than did CC 1. The drip-dry cotton CD 2 retained more original strength than did CD 1. Fabrics CC 2 and CD 2 are the more expensive fabrics in their groups. Since the fabrics in the glass fiber groups lost neither their original strength nor color, price was a factor only in the appearance and texture of GM 2, the most expensive, where different types of novelty yarns were used. Milium, the most expensive lining afforded the best preservation of color and strength.

CONCLUSIONS

Within the limits of this study the following general conclusions might be drawn:

1. Unbleached muslin lining seemed to improve the insulative value of the heavy type cotton drapery fabrics more than the other linings and seemed to retard the loss of single fabric strength about one-fourth. Colorfastness appeared to be lessened slightly. This is the least expensive lining.

2. Milium, the most expensive lining, seemed to afford the most protection against strength loss for the heavier type drapery fabric, reducing the loss for the single fabric by one-half or more. The original colors of these fabrics were retained. Milium seemed to rank next to unbleached muslin as a thermal insulator affording the best combination for the lightest weight of the heavier drapery fabrics.

3. The medium grade sateen seemed to prevent some loss of strength for the chintzes and the heavier type cotton drapery fabrics excluding the damask. This lining appeared to retard fading somewhat for all the heavier type drapery fabrics and the chintzes. Sateen improved the insulative value of the chintzes more when not exposed to convection currents but lessened the insulative value for the heavier cotton drapery fabric.

4. The chintz lining with chintz seemed to be comparable to the sateen lining with chintz both in durability and insulative value.

5. The glass fiber fabrics appeared to have no loss in strength or color. Opaque glass fiber drapery fabric appeared to have high

insulative value with and without convection currents while the marquisette weave glass fiber fabric appeared to have an inverse thermal reaction being the least effective of all fabrics when convection currents were present.

6. The drip-dry cotton fabrics with satin weaves seemed to vary in insulative value with the heaviest (CD 1) having the highest value with convection currents. Next to chintz they appeared to have the least strength loss of all the cotton drapery fabrics.

7. Price had a direct relationship with durability among the cotton fabric groups. However, price seemed to show no correlation with thermal insulation.

8. The thermal box method seemed to allow the sample to be exposed to the flow of convection currents. After more intensive study of the method, this may provide a more effective device for thermal conductivity of drapery fabrics.

RECOMMENDATIONS FOR FURTHER STUDY

Improvement of the thermal box method:

1. Once the box has reached temperature equilibrium continue the heat flow until all of the samples have been exposed.
2. A thorough check of convection currents may necessitate the use of screens.
3. To simulate heat loss as in winter weather hang the lined drapery with the drapery fabric toward the heat source.

Sampling:

1. Use a wider range of fiber groups.
2. Use more qualities of each type of lining fabric.

Effect of laundering:

1. Launder samples a specified number of times.
2. Note whether launderings alter the fabric and affect the thermal conductivity.

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APPENDIX

Table 1. Analyses of Variance for Thermal Conductivity per Unit Thickness

Source of variation	Degrees of freedom	Mean squares	F value
<u>Drapery classes</u>			
Total	10		
Between fabric classes, CT, CC, CD, GM and GO	3	.0068925	32.42**
Within classes	7	.0002126	
<u>Cotton classes</u>			
<u>Cotton vs glass fiber fabrics</u>			
Total	10		
GM + GO vs CT + CC + CD	1	.0184359	87.81**
Among cotton classes CT, CC, CD	2	.0011208	5.33*
Within classes	7	.0002126	
<u>Linings</u>			
Total	16		
Among linings LM, LU, LS, LC with CT 1, 2, 3 and CC 1, 2	3	.0001287	.14
Within fabrics	13	.0009378	

* Significant at P = .05
** Significant at P = .01

Table 2. Analyses of Variance for Thermal Conductivity in Watts Per Hour

Source of variation	Degrees of freedom	Mean squares	F value
<u>Drapery classes</u>			
Total	10		
Between fabric classes, CT, CC, CD, GM and GO	3	238.53	1.24
Within classes	7	191.86	
<u>Cotton classes</u>			
<u>Cotton vs glass fiber fabrics</u>			
Total	10		
GM + GO vs CT + CC + CD	1	678.65	3.05
Among cotton classes CT, CC, CD	2	18.30	.09
Within classes	7	191.86	
<u>Glass fiber marquisette vs other classes</u>			
Total	10		
Among GM's	1	45.13	.03
GM vs CT, CC, CD and GO	1	2019.65	12.02**
Within classes	8	167.88	
<u>Linings</u>			
Total	16		
Among linings LM, LU, LC, LS with CT 1, 2, 3 and CC 1, 2	3	15.61	4.09*
Within fabrics	13	3.82	

* Significant at P = .05
** Significant at P = .01

Table 3. Analyses of Variance for Breaking Strength After 200 Hours Exposure in the Fade-Ometer

Source of variation	Degrees of freedom	Mean Squares	F value
Textured cottons-linings, LM, LU, LS			
Warp			
Total	35		
Among fabrics, CT 1,2,3	2	2375.02	159.50**
Linings in fabrics	3	238.32	16.01**
Interaction: Fabric x lining	6	14.89	
Within fabrics	24	16.65	1.12
Textured cottons-lining LM			
Warp			
Total	17		
Among fabrics CT 1,2,3	2	1331.37	49.44*
Fabric alone vs lined LM	1	696.89	25.88*
Interaction: Fabric x lining	2	26.93	
Within fabrics	1	17.04	.63
All drapery fabrics			
Warp			
Total	65		
Among fabrics CT, CD, CC, GM, GO	10	3418.07	.56
New fabrics vs 200 hours exposure	1	443649.12	72.51**
Interaction: Fabric x time	9[1]	6131.58	
With fabrics	44	6113.21	.10

* Significant at P = .05
** Significant at P = .01
[1] 1 DF deleted for missing plot

Table 4. Analysis of Covariance for the Effect of Additional Hours of Exposure in the Fade-Ometer on Warp Breaking Strength

Fabric	(b)+=	(r)++	(F)"
CT 2	- .088	- .97	
CT 2 + Lining LS	- .046	- .89	38.01**
CT 2 + Lining LM	- .017	- .52	79.71**
CT 3	- .053	- .87	
CT 3 + Lining LS	- .041	- .74	40.00**
CT 3 + Lining LM	- .028	- .71	41.42**
CC 2	- .008	- .64	
GM 2	+ .006	+ .49	
GO 1	+ .019	+ .76	

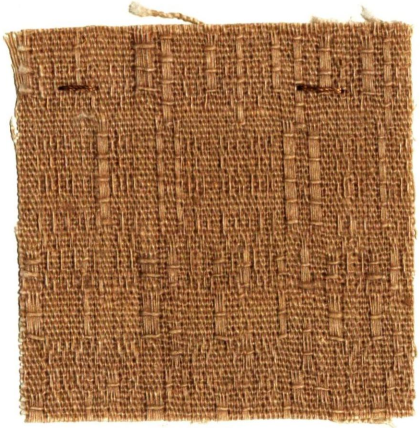
+= b = The regression coefficient, for every hour of exposure in the Fade-Ometer. There are (b) lbs of loss in breaking strength.

++ r = Correlation of hours in the Fade-Ometer related to breaking strength.

" F = Heterogeneity between lined vs unlined fabric.

** = Significant at 1.0 percent level.

Exhibit I. Swatches of Experimental Materials

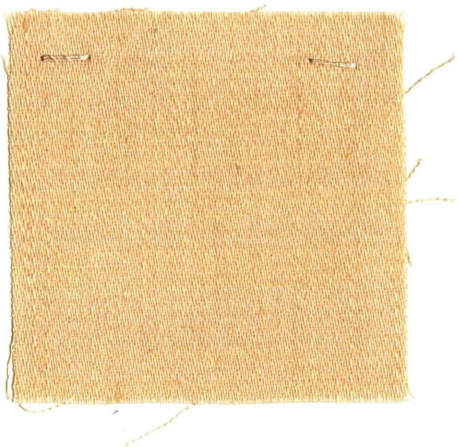


Textured cotton 1

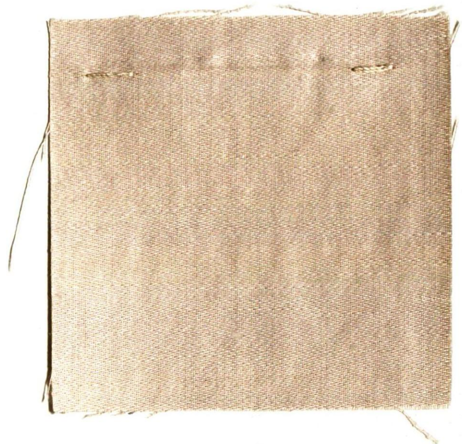
Textured cotton 2

Textured cotton 3

Exhibit I, continued



Cotton drip-dry 1

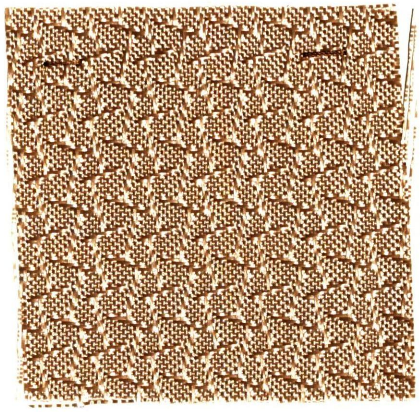


Cotton drip-dry 2

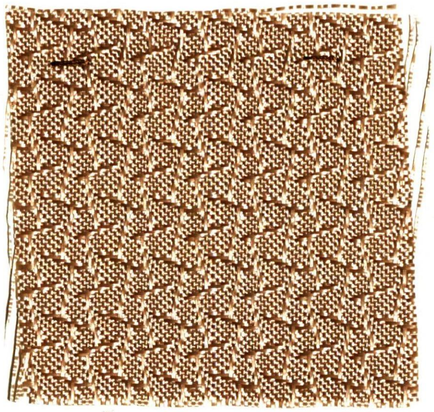
Cotton chintz 1

Cotton chintz 2

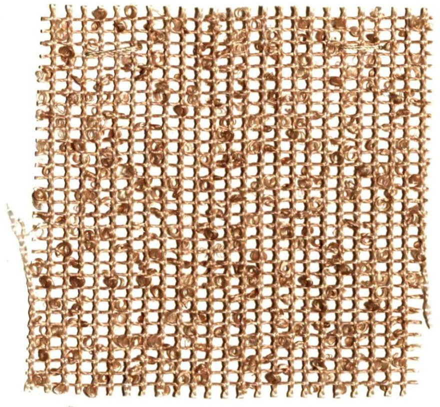
Exhibit I, continued



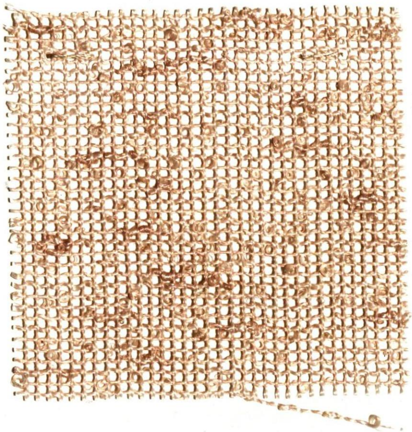
Glass fiber opaque 1



Glass fiber opaque 2



Glass fiber marquisette 1

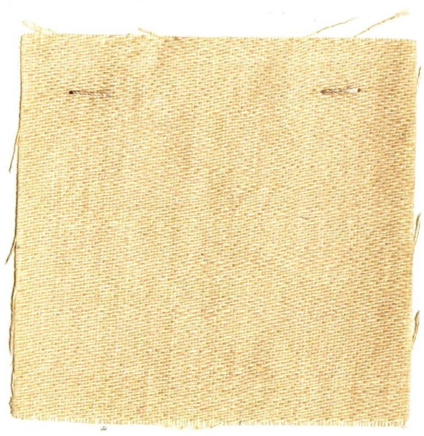


Glass fiber marquisette 2

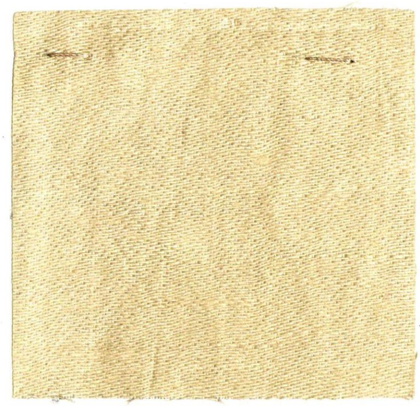
Exhibit I, continued

Cotton chintz lining

Unbleached muslin lining



Sateen cotton lining



Milium-cotton sateen lining