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SUBJECT:

THERMAL PROPERTIES OF WALLCOVERINGS

I have attached an article that describes a university study on the thermal properties of wallcoverings. The study included various vinyl coated and fabric wallcoverings. The results of the study included a calculated value for the specific thermal conductivity coefficient (K) of each sample. The article related these "K" values to the thermal insulation properties of the wallcoverings. In particular, the greatest amount of insulation was provided by wallcoverings which had the lowest K values. While the article did not correlate the measured K values to actual energy savings, it did reference a report that stated most homes lose 17% of their heat through the walls. The inference was that some or all of the heat loss could be reduced through the use of insulative wallcoverings. Based on the types of fabric wallcovering samples that we are now receiving, I believe we could determine and assign K values to these materials. I'd appreciate your comments on the marketing value of this subject.

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Thermal Properties of Wall Covering Materials

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ABSTRACT

A major source of heat loss in homes is through walls. Increased insulation on interior walls may reduce energy consumption for heating and cooling. This study evaluated the thermal transmittance characteristics of 15 wall coverings that differed in weight, thickness, density, fiber content, and construction characteristics. A guarded hot/cold plate was used to measure the thermal conductivity of the fabrics. Significant differences in thermal transmittance were found among some of the wall coverings evaluated.

Introduction

Since the dawn of civilization, man has used various means for achieving warmth, fulfilling a basic need of protecting the body against harsh elements. Methods to improve housing throughout the ages in terms of aesthetics as well as thermal comfort include the use of a variety of wall covers on interior walls. Primitive man achieved added warmth by hanging animal skins, while centuries later, fine tapestries kept drafts to tolerable levels in medieval buildings. It was much later, however, that wallpaper achieved a universal acceptance, when it was considered aesthetically pleasing, economical, and functional (*i.e.*, provided acoustical insulation and reduced maintenance on interior surfaces) [4, 17]. Today, there is an increasing demand for textile products to cover interior walls in residential and commercial buildings as a replacement for wallpaper [15, 16].

Many kinds of fabric and paper constructions made from both natural and man-made fibers are used as wall coverings, ranging from flocked and printed papers, grasspapers, simulated suedes, and jute fabrics laminated to a paper base, to thicker fabric constructions similar to those used as floor covering materials [3, 13]. Present concerns for energy conservation have compelled specifiers and users to shift concerns from price, design, etc., to thermal insulation and other functional qualities when selecting wall covering materials. Because of the price and application difficulties encountered when traditional floor coverings were applied to interior walls, heavier textile products with increased insulation are now being specifically designed as wall coverings.

Several studies have investigated the thermal insulative properties of carpeting [5, 6, 7, 11]. The Carpet and Rug Institute stated that carpets and rugs may have potential for reducing energy consumption for heating and cooling, especially when installed on ground floors [6, 7]. Birchfield and co-workers [6], using computer simulation of heat transfer in residential and light commercial structures, estimated the energy and cost savings resulting from the installation of various carpet assemblies. Hager [10] contends, however, that the energy-saving potential of floor coverings is less significant because the percentage heat loss through ground floors is minimal, and only a small fraction of the heat loss would be saved by adding floor coverings.

In contrast, the building industry statistics estimate that walls are major contributors to heat loss. A report from the California Energy Commission [11] states that the major source of heat loss in homes is through walls. Dow Chemical Company estimates that a typical house with moderate amounts of insulation loses up to 17% of its heat through the walls [9]. Many of the homes in California, as in other states, are energy inefficient and poorly insulated because they were built during a time when energy was cheap and plentiful. Thus, wall insulation in these homes is often inadequate. Because of the larger percentage of wall area, there is a greater opportunity to save energy with wall coverings, compared to floor coverings.

Studies by Haynes [11], Ball [5], and the Carpet and Rug Institute [6, 7] showed that the thermal conductivity of a floor covering material is inversely proportional to thickness. Other researchers also showed a linear relationship between thermal resistance and the thickness of a textile product [14]. Since the thermal insulative value of air is significantly greater than that of fibers, the insulative properties of a textile

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material are largely dependent on the amount of air trapped within its structure [8, 14]. Both density and thickness determine the thermal insulation potential of a textile. Napped and pile fabrics, for example, usually have a greater thermal insulating value than do fabrics with smooth surfaces. Polyurethane and polyester foams with fine pore structures trap air more effectively than do fabric structures and, hence, have good insulating efficiency [14]. Thus, wall coverings with increased thickness and ability to trap air may significantly reduce energy consumption for heating and cooling in residential and commercial structures. One such material is a nonwoven polypropylene wall covering material that was designed to provide both thermal and acoustical insulation. According to Protospataro and Oliviera [15, 16], the product's thermal insulation depends on both the characteristics of the component fibers and the structure of the fabric itself.

The construction characteristics of wall coverings are an important criterion for selection, both from the aesthetic and functional standpoint. Leuman [13] states that surface quality or texture, because of its insulating ability, is often chosen over color and other desirable characteristics. The nonwovens, for example, have disadvantages such as instability, susceptibility to indentation, and problems in application. Consequently, nonwoven fabrics have not achieved the status of more traditional wall covering materials.

Few studies have evaluated the thermal characteristics of textile products suitable for wall coverings. Our study evaluates the thermal insulative properties of selected wall covering fabrics differing in fiber and fabric construction characteristics and type of primary backing. The wall covering fabrics evaluated included natural and man-made fibers, nonwoven and woven fabrics, and cork fabrics. Additional factors considered when selecting the test fabrics were availability in continuous form, compressibility, dimensional stability, popularity, and functionality such as acoustical and potential insulative properties. The study was limited, however, to evaluating the thermal insulative properties, thickness, weight, bulk density, fiber content, and construction characteristics of the wall covering fabrics.

Experimental Procedure

MATERIALS

Fifteen wall coverings were tested; they were selected as representing a variety of both natural and man-made fibers and materials, and woven and nonwoven fabric constructions. The fiber content, construction characteristics, weight, thickness, and density of the wall covering materials are presented in Table I. Photographs and illustrations depict surface and construction characteristics (Figures 1 and 2).

Three specimens measuring 52 × 52 cm were randomly cut from a 2 m length of each wall covering material. All test specimens were placed under standard conditions (65 ± 2% RH and 21 ± 1°C) for 24 hours prior to testing for thickness, weight, and thermal properties.

TABLE I. Construction characteristics of wall covering fabrics.

Fabric	Weight, g/m²	Thickness mm	Bulk density kg/m³	Face	Backing
A	637.43	0.914	697.41	natural cork, seam sliced veneer	100% cotton, 51 × 45 plain weave
B	568.60	1.422	399.86	natural cork, random sliced veneer	100% cotton, 51 × 46 plain weave
C	464.17	2.235	207.68	natural cork, 6 mm granules	100% cotton, 74 × 40, 2/1 twill
D	718.81	1.219	589.67	expanded vinyl	100% cotton, 64 × 41 plain weave
E	727.62	1.295	561.87	expanded and embossed vinyl	100% cotton, 64 × 41 plain weave
F	435.01	1.600	271.88	acrylic and modacrylic novelty yarns	paper
G	335.33	1.016	330.05	jute warp, polyester filling	paper
H	328.55	0.864	380.27	100% flax, 25 × 21 plain weave, pigment print	none
I	361.78	1.118	323.60	100% flax, 10 × 10 plain weave	paper
J	567.25	1.194	475.08	cotton warp, flax filling	paper
K	451.63	1.854	243.60	100% wool, 16 × 12 plain weave	paper
L	587.60	2.438	241.02	cotton filling, paper warp	paper
M	1,985.20	5.690	348.89	100% sisal, vertical cords	latex
N	2,306.96	6.071	380.00	100% sisal, vertical braids	100% jute
O	2,878.96	7.087	406.23	blend of wool, mohair, rayon, nylon, modacrylic; unitary fusion bonded concentric rib	100% jute

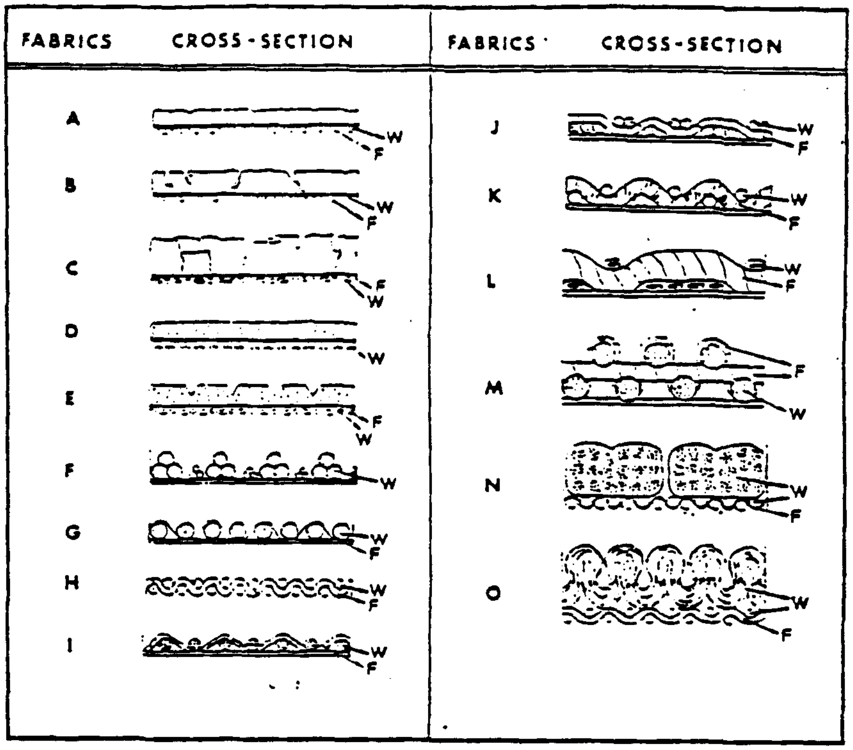

FIGURE 1. Cross sectional diagrams of wall covering fabrics (W = warp and F = filling).

The construction characteristics and fiber contents of the face and backing materials in the wall coverings were evaluated according to the procedures in the following standard test methods: ANSI/ASTM D 418, Woven and Tufted Pile Floor Coverings; ANSI/ASTM D 1910, Construction Characteristics of Woven Fabrics; ANSI/ASTM D 2646, Testing Backing Fabrics; and AATCC Test Method 20, Fibers in Textiles: Identification [1, 2].

A fiberglass insulating board with a known thermal conductivity value was obtained from the National Bureau of Standards and used to calibrate the guarded hot/cold plate.

Thickness

The procedures in ANSI/ASTM D 1777, Measuring Thickness of Textile Materials [2] were used to measure the thickness of the wall covering materials. Thickness measurements were taken with a Frazier Compressometer under 0.07 k N/m^2 load, using a presser foot with a 7.6 cm diameter. An average of five readings was recorded for the thickness of each specimen.

Fabric Weight and Bulk Density

Fabric weight in g/m^2 for each wall covering was based on the average weight of three 25.4×25.4 cm specimens [2]. Bulk density was calculated as follows [2]:

$$B = W/t \quad .$$

where B = bulk density, kg/m^3; W = mass/unit area of fabric, g/m^2; and t = thickness of fabric, mm.

Thermal Transmission

The procedure in ANSI/ASTM D 1518 [1] was used to measure the thermal transmission characteristics of the wall covering fabrics. The testing instrument was a guarded hot/cold plate, constructed at Kansas State University for the Department of Clothing, Textiles and Interior Design, and housed in the Institute for Environmental Research. The guarded hot/cold plate is composed of a test plate and a guard ring, which can be maintained at a constant temperature during testing. Thermal transmittance was measured by the rate of heat loss through the fabric into

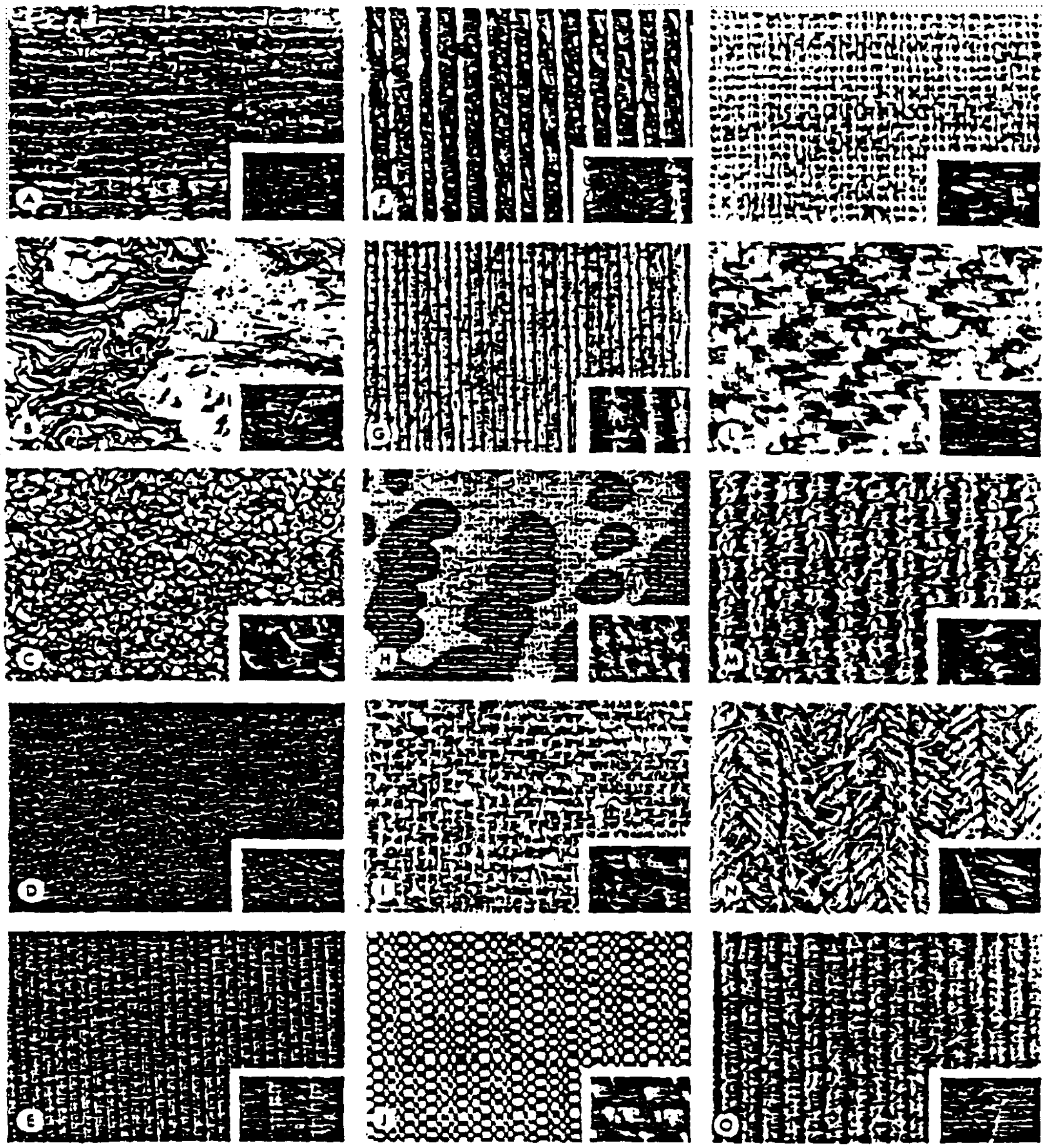

FIGURE 2. Photographs of wall covering fabrics.

the air by recording the amount of energy required to maintain the test plate at a constant temperature.

To determine the amount of power loss, we first calibrated the instrument by using a material with a known thermal conductivity coefficient: a fiberglass insulation board from the National Bureau of Standards.

The guarded hot/cold plate was operated in a Sherer environmentally controlled test chamber which measured 2.44 × 3.05 m. The test conditions in the chamber were 20.25 ± 0.5°C, 50% RH, and air velocity of approximately 10 cm/second. The temperature of the test plate and guard ring was maintained at 34.0 ± 0.4°C. After the specimens had reached equilibrium with the conditions in the test chamber, readings from the specimens were taken every 3 minutes over a 30 minute period, resulting in 10 readings per test.

The intrinsic thermal transmission coefficient of the test fabric alone, U_2, was calculated using Equation 1, based on values derived from the combined heat or thermal transmittance coefficient of the specimen plus air, U_1, and the bare plate thermal transmittance coefficient, U_{bp}. Equation 2 was used to calculate U_1, and U_{bp} was similarly calculated using the bare plate thermal transmittance coefficients. U_1, U_2, and U_{bp} were expressed in Btu/h · ft² · °F.[1]

$$U_2 = (U_{bp} \times U_1)/(U_{bp} - U_1) \quad (1)$$

$$U_i = (P/(A \times (T_p - T_a)) \quad (2)$$

where P = power loss from test plate, Btu/h; A = area of test plate, ft²; T_p = test plate temperature, °F; and T_a = air temperature, °F.

After the thermal transmittance coefficient had been calculated, U_2, the specific thermal conductivity coefficient for a unit thickness of test specimen, k, also was calculated using Equation 3

$$k = U_2 \times \text{thickness, in.} \quad (3)$$

Results

CONSTRUCTION CHARACTERISTICS

The wall coverings evaluated in this study were representative of the types currently available for residential and commercial interiors. Fabric weights ranged from 328.55 g/m² (9.69 oz/yd²) to 2,878.96 g/m² (84.9[illegible] oz/yd²). Similarly, fabric thickness ranged from 0.864 mm (0.034 in.) to 7.087 mm (0.279 in.) Fabric construction types included three cork materials laminated to cotton backings (fabrics A, B, and C); two expanded vinyls laminated to cotton backings (fabrics D and E); six medium-weight fabrics in which yarns or woven fabrics were bonded to paper backings (fabrics F, G, I, J, K, and L); one unbonded, pigment-printed linen (fabric H); two heavy-weight, 100% sisal fabrics with a latex backing or bonded to jute (fabrics M and N); and a unitary, fusion-bonded, concentric rib fabric (fabric O). Fabrics M, N, and O were similar in weight and thickness to textiles used for floor coverings.

Photographs of the fabric surfaces and schematic drawings of their cross sections illustrate the construction details (Figures 1 and 2).

[1] To convert to W/(m² · K), multiply by 5.67.

THERMAL CONDUCTIVITY

Mean thermal transmittance coefficients (U_2) and specific thermal conductivity coefficients (k) for the wall coverings as measured by the guarded hot/cold plate are reported in Table II. The analysis of variance statistical test showed that differences among the 15 wall coverings were significant at the 1% level for both the thermal transmittance (U_2) and thermal conductivity coefficients (k).

TABLE II. Thermal conductivity of wall covering fabrics.

Fabric	Thermal transmittance coefficient (U_2) Btu/h · ft² · °F[a]	Specific thermal conductivity coefficient (k) Btu · in/h · ft² · °F[b]
A	4.444	0.160
B	4.206	0.236
C	3.489	0.307
D	6.129	0.291
E	6.502	0.332
F	4.354	0.275
G	6.703	0.268
H	5.144	0.175
I	5.630	0.248
J	5.160	0.243
K	3.724	0.272
L	3.377	0.324
M	2.688	0.602
N	2.260	0.504
O	1.654	0.462

[a] To convert to W/(m² · K), multiply by 5.67. [b] To convert to W/(m · K), multiply by 0.144.

In general, the thermal transmittance coefficients (U_2) were inversely proportional to the thickness of the wall coverings. The Duncan's Multiple Range Test (Table III) was performed on mean thermal transmittance coefficients to identify significant differences in the thermal properties among the wall coverings.

The thinnest fabrics (*i.e.*, fabrics G, E, D, I, J, H, and A) exhibited the highest thermal transmittance coefficients or were the poorest insulators. Fabric G, which was constructed from heavy jute yarns interlaced with a fine polyester filling, exhibited the highest thermal transmittance coefficient (*i.e.*, was the poorest insulator), even though it was slightly thicker than fabrics H (100% flax) and A (natural cork, seam sliced veneer). This may be attributed to the paper backing, the lower insulative properties of the jute fibers, and the spaces between the warp yarns.

The expanded vinyls (fabrics D and E) also exhibited significantly higher thermal transmittance coefficients than fabrics I, J, H, and A, which had considerably lower thickness values. The latter wall cov-

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TABLE III. Duncan's multiple range test for the thermal transmittance coefficients of wall covering fabrics.

Fabric	Thermal transmittance coefficient (U_2) Btu/h · ft² · °F[a]	Groupings[b]
G	6.703	*
E	6.502	**
D	6.129	**
I	5.630	**
J	5.160	*
H	5.144	*
A	4.444	*
F	4.354	*
B	4.206	**
K	3.724	**
C	3.489	*
L	3.377	**
M	2.688	*
N	2.260	*
O	1.654	*

[a] To convert to W/(m² · K), multiply by 5.67. [b] Means connected by asterisks are not significantly different, alpha level = 0.05.

erings were either woven fabrics or seam sliced veneer cork.

The thickness and thermal transmittance coefficients for the thicker wall coverings were inversely correlated (*i.e.*, thickness: fabrics K < C < L < M < N < O; thermal transmittance [U_2]: O > N > M > L > C > K). The fusion bonded concentric rib fabric (fabric O) had a U_2 of 1.654 which was significantly lower than all other fabrics tested. It thus provided the greatest amount of insulation against heat loss.

Thermal conductivity coefficients (k) were calculated to ascertain the effects of fiber type and yarn and fabric construction characteristics on thermal conductivity per unit thickness (Btu · in/h · ft² · °F).[2] The rank order of the thermal conductivity coefficients (k) differed from the thermal transmittance coefficients (U_2), indicating that fiber and fabric construction characteristics significantly affected the thermal insulative properties of the wall coverings.

The Duncan's Multiple Range Test (Table IV) showed that the 100% sisal wall coverings (fabrics M and N) provided the least amount of insulation per unit thickness. This may be attributed to fabric construction characteristics (*i.e.*, lengthwise braids) or the inherent characteristics of the sisal fibers, such as lack of fiber crimp and length of the staple. The spaces between the vertical ribs in fabric M may have contributed to its high thermal conductivity coefficient, which was significantly greater than that of fabric N.

TABLE IV. Duncan's multiple range test for thermal conductivity coefficients of wall covering fabrics.

Fabric	Specific thermal conductivity coefficient (k) Btu · in/h · ft² · °F[a]	Groupings[b]
M	0.602	*
N	0.540	*
O	0.462	*
E	0.332	*
L	0.324	**
C	0.307	***
D	0.291	***
F	0.275	***
K	0.272	*****
G	0.268	***
I	0.248	**
J	0.243	**
B	0.236	*
H	0.175	*
A	0.160	*

[a] To convert to W/(m · K), multiply by 0.144. [b] Means connected by asterisks are not significantly different, alpha level = 0.05.

The unitary fusion bonded, concentric rib (fabric O), which was a blend of wool, mohair, rayon, nylon, and modacrylic fibers, exhibited a significantly lower thermal conductivity coefficient than did the 100% sisal fabrics (fabrics M and N), but the value was significantly higher than values obtained for the other wall coverings. The spaces between the vertical ribs may have contributed to the increased heat loss.

We observed no significant differences in thermal conductivity among fabrics E (expanded and embossed vinyl with vertical ribs), L (cotton filling and paper warp), and C (natural cork with 6 mm granules). These wall coverings ranked below fabrics M, N, and O, as described above, and thus exhibited greater thermal insulation. The other cork wall cov-

[2] To convert to W/(m · K), multiply by 0.144.

erings showed significantly lower thermal conductivity values than did the wall covering constructed from cork granules. Once again, the loss of insulation in the granulated cork fabric may be attributed to the appreciable spaces between the 6 mm granules that adhered to the primary backing.

The expanded vinyl with vertical ribs (fabric E) had poorer insulative properties than did the expanded vinyl without vertical ribs (fabric D).

We observed no significant differences in thermal conductivity for fabrics F (acrylic and modacrylic novelty yarns laminated to paper), K (100% wool laminated to paper), G (jute warp and polyester filling laminated to paper, I (100% flax plain weave laminated to paper), and J (cotton warp and flax filling laminated to paper). It appeared to us that the paper backing negated differences in thermal conductivity among these various fiber and fabric types; however, the complex interaction between backing, fiber type, and yarn and fabric construction characteristics must not be oversimplified. Further research is needed to evaluate the effects of various backing materials on the thermal conductivity of wall coverings.

Fabrics B (natural cork, random sliced veneer), H (100% flax), and A (natural cork, seam sliced veneer) exhibited the lowest thermal conductivity coefficients or provided the greatest amount of insulation. Even though the fiber microstructure, long staple length, and low crimp in flax fibers usually provides less insulation than highly crimped, short staple length fibers such as wool or texturized synthetic fibers, the balanced weave and absence of paper backing in Fabric H may have contributed to its lower thermal conductivity values.

Conclusions

Fifteen wall covering fabrics that may have potential for reducing heat loss through interior walls in residential and commercial buildings were evaluated for thermal characteristics using a guarded hot/cold plate. The fabrics differed in weight, thickness, fiber content, type of backing, and construction characteristics.

Thermal characteristics evaluated included thermal transmittance (U_2) and specific thermal conductivity coefficient (k), which is based on heat loss or conductivity per unit thickness.

Results showed that vertical cords, braids, and ribs increased heat loss in the wall covering fabrics. Similarly, granulated cork wall coverings with appreciable spaces between the granules exhibited higher conductivity than did veneer-type cork fabrics. Additional research is needed to assess the effects of the backing material on the thermal characteristics of wall coverings.

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