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Radiant Heating in Seamless Flooring - A Feasibility Study

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Final Report

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Radiant Heating in Seamless Flooring - A Feasibility Study

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The purpose of this study was to determine the feasibility of using radiant heating in seamless flooring as a supplemental heating source in housing units. The resistance of twenty seamless flooring systems to abrasion, flow, impact, flame, stain, moisture and elevated temperature were evaluated using laboratory tests. Power requirements and the magnitude and uniformity of surface temperatures of nine electrical heating elements, functioning as radiant heating panels, were experimentally determined and evaluated. The radiant heating panels were coated with selected seamless flooring systems and the performance characteristics of the radiant panel-seamless flooring system were evaluated. The report contains a summary of test results demonstrating the feasibility of the radiant panel-seamless flooring system and the identification of areas for future research.

Key words: Electrical heating elements; materials performance; radiant panel-seamless flooring system; seamless flooring; temperature characteristics.

A. INTRODUCTION

The problems of energy conservation are of national concern. They are also of importance to the Maintenance Engineering Branch of Housing Management (HUD) since much energy is used in the public housing which they maintain. Many public housing units have a disproportionate share of the elderly and the very young and adequate temperatures are especially important for these occupants. Overall, the availability of adequate and economical heating sources has a direct bearing on the health and comfort of all housing occupants.

A novel approach to the supplemental heating of housing units is through electrical heating elements in a seamless flooring system. A possible advantage of radiant heating is that its use may permit the reduction of ambient temperatures without causing discomfort to housing occupants. In addition, it is expected that the low operating temperatures should lead to safe and durable heating systems. However, there are a number of questions about the use of radiant heaters in seamless flooring installations which need to be answered before their use can be recommended. These concern 1) cost effectiveness, 2) safety, and 3) compatibility between the seamless flooring and the heating element. These questions were addressed in the project described in this report.

B. OBJECTIVES

The objectives of the report are as follows:

1. to prepare a literature survey on the feasibility of a radiant panel-seamless flooring system.

2. to prepare and evaluate the performance of a small-scale laboratory system constructed from commercially available seamless flooring systems and radiant heating components.

3. to recommend heating components and flooring finishes which are likely to provide an effective heating system.

4. if the radiant heating concept is feasible, to identify and recommend areas for future research and development.

C. LITERATURE SURVEY

The survey of the literature applicable to the radiant panel-seamless flooring system was divided into three broad categories 1) seamless flooring, 2) radiant heating elements, and 3) the radiant panel-seamless flooring system. Sources of information included the 1974 Directory and Buying Guide Issue of Flooring, the Association of Seamless Applicators (ASA), National Association of Decorative Architectural Finishes (NADAF), the Seamless Systems Manufacturers' Committee of the National Paint and Coating Association (NPCA), National Electrical Manufacturers Association (NEMA), Underwriters' Laboratories (U.L.), Electrical Research Association (ERA-UK), and the Emerson Electrical Institute. In addition, the following computer data bases were utilized: Chemical Abstracts, NTIS, Compendex, and NAL/Cain.

C.1 Seamless Flooring

The modern seamless flooring system was developed in Germany in the 1940's and introduced into the U.S.A. in the early 1960's [1]. These systems are used in apartments, homes, hospitals, schools, offices, cafeterias, and nuclear plants [2, 3]. The advantages of using seamless flooring include easy maintenance, abrasion, impact and chemical resistance, moisture resistance, and the availability of a wide variety of decorative patterns [2, 3, 4].

The floor coating may be based on urethane, epoxy, polyester, or acrylic resins or in various resin combinations. Aggregates such as vinyl chips, metallic chips, quartz, and marble may be embedded into the base coat for decorative purposes. While such systems have been installed over many substrates, e.g., concrete, plywood, and vinyl tile, careful preparation of the substrate is essential for successful installation. Detailed instructions for substrate preparation are given in the Association of Seamless Applicators Handbook for Seamless Flooring [5] as well as in the descriptive literature provided by manufacturers of seamless flooring components. The many polymeric types of seamless flooring (listed as monolithic flooring) are listed in the 1973 Directory and Buying Guide Issue of Flooring [6].

C.2 Radiant Heating Elements

Radiant heaters transfer radiant energy in the infrared range to objects and surfaces in the line of sight from the radiation source. Radiant electrical heaters may be placed in two broad categories, a) low intensity heaters which operate at temperatures less than 500°F (260°C) and b) high intensity heaters which operate at temperatures greater than 500°F (260°C) [7]. Low intensity radiant heaters include ceiling cable, cable (or panels) in the floor, ceiling panels, and wall panels; their heating elements consist of electrical resistive wires, films, or ribbons. High intensity heaters are beyond the scope of this project, but examples are quartz lamp heaters, infrared lamps, open-wire ribbon and glass panel heaters.

With few exceptions, building code authorities in the U.S.A. require that electrical wiring and equipment in buildings, including radiant heating cable and panel installations, comply with applicable provisions of the National Electric Code (NEC). The NEC does not permit heating cables in walls; heating cables are permitted on dry board, in plaster and on concrete ceilings. The NEC permits both panels and cables to be installed in floors, provided they are in poured concrete or masonry [8].

Protection must be provided against electric shock, fire hazards, contact with electrical conductors, and the effects of mechanical abuse, corrosion, and vibration. Innovations in electrical systems would have to be approved by NEC before any use beyond the prototype stage. The use of safety devices such as ground fault circuit interrupters and the use of voltages less than 40V might be required.

The U.L. Electrical Appliance and Utilization list was used to identify manufacturers of electrical radiant heating cables and panels [9]. Electrical radiant heating floor systems are used extensively in Europe and the Electrical Research Association (ERA) list of radiant heating sources was utilized to identify foreign manufacturers. In addition, innovative heating elements included a conductive nonwoven graphite fabric, polyester-laminated heating elements and conductive paints.

C.3 Radiant Panel-Seamless Flooring System

The literature surveyed showed the radiant panel-seamless flooring system to be innovative. However, Salter [10] has described a quick response system generally called the "under floor coverings heating method" which utilizes electric cable floor heating and where the quick response system reaches acceptable temperature within 20 minutes after the power is turned on. It has apparently been used with other floor coverings such as rugs, wood parquetry, and vinyl tile. Figure 1 is an adaptation of a Salter drawing relating to radiant heating in flooring and the potential use of seamless flooring as part of the system.

An Australian study [11] investigated the physiological aspects of electrical radiant heat. Among their conclusions were the following: 1) in order for the human body to be comfortable, the body should not lose heat to the environment, 2) special thermal sensitivities of the body are related primarily to the head and feet, 3) extended heating of the head by radiation leads to discomfort and possible distress, 4) the feet and legs become colder as the ambient temperature falls below 60°F (16°C) because of restriction of blood flow to the legs and the feet are likely to feel uncomfortable if ambient conditions exceed 80°F (27°C). The study concluded that the rate at which heat is released from a heated floor should be such that the floor temperatures are a little below 80°F (27°C).

C.4 Summary

The literature survey of seamless flooring systems indicated that these systems are available in a wide variety of compositions of base coat, glaze coat, finish coat, and the decorative aggregates. While the majority of systems utilize polyurethane resins in the finish coat, other systems included water-thinned urethane, epoxy, acrylic, and moisture-resistant solvent-thinned urethane resins.

The review of the literature on heating elements for potential use in a radiant panel-seamless flooring system indicated that no data on cost-effectiveness studies were available. An innovative electrical system would have to be approved by the National Electric Code (NEC) for any use beyond a prototype study. At present, NEC only approves electrical radiant heating elements buried six inches in a concrete slab.

D. PERFORMANCE TESTS

The evaluation of the seamless flooring system involved test methods and procedures which would simulate conditions encountered in use in public and other housing. The test procedures used were generally modified from ones given in Military Specification MIL-D-3134F, "Deck Covering Materials," Federal Specification TT-C-001685, "Coating System - Decorative

Figure 1. **RADIANT HEATING IN SEAMLESS FLOORING**

CONCRETE FLOOR

WOOD FLOOR

and Protective, Seamless," in relevant ASTM standards or in Fed. Test Method Std. No. 141a. Tests included abrasion resistance, resistance to elevated temperature (flow or slip), impact resistance, stain resistance, flammability and heat stability. Since the radiant panel-seamless flooring system would be expected to be used with ground fault circuit interrupters and at voltages less than 40V, electrical shock measurements were not determined. However, these measurements would be expected to be included in any acceptance tests.

While seamless floorings (monolithic flooring) have been used since the early 1960's, their suitability as coatings for radiant heating elements have not been established. In this phase of the study, the performance of the radiant heating panel was studied separately and in conjunction with seamless flooring coating systems. Voltage and power requirements, surface temperatures and uniformity of heat distribution, and their effect on the seamless flooring resins were of concern in studying the radiant heating panels.

Each seamless floor system was prepared using the procedure recommended by the manufacturer. However, every system fits into the ASA-PFU-S category, and thus, the thickness of each system was 35 mil (0.889 mm) minimum as described in ASA "1973-74 Specifications Handbook for Seamless Flooring."

The steel panels used as substrate for many of the performance tests were from Type R, Q-Panels, 0.032 in (0.813 mm), cold rolled, low carbon steel (ASTM D609, Type 1-B). The plywood panels used as substrate for the performance testing of the radiant heating elements were 3/4 in x 24 in x 24 in (19 mm x 609 mm x 609 mm) conforming to Exterior AC Grade, Species Group 1 (Voluntary Product Standard PS 1-74), American National Standard A 199.1-1974).

D.1 Materials Selection

The seamless flooring systems used in this feasibility study were selected to give a wide range of generic resin types, e.g., urethane, acrylic; but none of the systems was specifically designed to be heated for any length of time or for use with heating elements. Also, the heating elements used in the study were designed for ceiling and wall use rather than for use on floors.

The materials used in the performance tests described here are listed by numerical key as follows and the order of application for each system is given:*

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* Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Ino case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

System			Manufacturer
#1	A.	Epoxy base coat	General Polymers Corp. 3925 Huston Avenue Cincinnati, OH 45212
	B.	Epoxy resin glaze	
	C.	Granules	
	D.	Epoxy sealer	
#2	A.	Epoxy base coat	General Polymers Corp. 3925 Huston Avenue Cincinnati, OH 45212
	B.	Vinyl chips	
	C.	Polyurethane glaze	
#3	A.	Epoxy base coat	General Polymers Corp. 3925 Huston Avenue Cincinnati, OH 45212
	B.	Seal coat	
	C.	Vinyl chips	
	D.	Epoxy glaze	
#4	A.	Epoxy base coat	General Polymers Corp. 3925 Huston Avenue Cincinnati, OH 45212
	B.	Seal coat	
	C.	Vinyl chips	
	D.	Urethane glaze	
#5	A.	Epoxy base coat	Lehn & Fink Industrial Products Division Sterling Drug, Inc. Montvale, NJ 07645
	B.	Granules	
	C.	Epoxy top coat	
#6	A.	Acrylic base coat	Zurock, Inc. 7300 Natural Bridge St. Louis, MO 63121
	B.	Vinyl chips	
	C.	Acrylic top coat	
#7	A.	Urethane base	Wilmington Chemical Corp. Pyles Lane Wilmington, DE 19899
	B.	Urethane top coat	
#8	A.	Epoxy base	Dur-A-Flex, Inc. 100 Meadow Street Hartford, CT 06114
	B.	Vinyl chips	
	C.	Epoxy seal	
	D.	Epoxy glaze	
#9	A.	Epoxy base	Cambridge Tile Mfg. Company P.O. Box 71 Cincinnati, OH 45215
	B.	Vinyl chips	
	C.	Urethane top coat	
#10	A.	Epoxy base	Cambridge Tile Mfg. Company P.O. Box 71 Cincinnati, OH 45215
	B.	Granules	
	C.	Epoxy top coat	
#11A	A.	Urethane base coat	M-R Plastics & Coatings Inc. 11460 Dorsett Road Maryland Heights, MO 63043
	B.	Urethane top coat	
#11B	A.	Epoxy base coat	M-R Plastics & Coatings Inc. 11460 Dorsett Road Maryland Heights, MO 63043
	B.	Urethane top coat	

#12	A.	Urethane base coat	Southern Imperial Coatings Corp. 16362 Chef Menteur Highway New Orleans, LA 70129
	B.	Vinyl chips	
	C.	Urethane glaze coat	
#13	A.	Epoxy base coat	McDevco Inc. 27692 Camino Capistrano Laguna Niguel, CA 92677
	B.	Vinyl chips	
	C.	Epoxy top coat	
#14	A.	Epoxy base coat	Key Laboratories 1181 Baskins Road Largo, FL 33540
	B.	Vinyl chips	
	C.	Epoxy-acrylic glaze coat	
#15	A.	Epoxy base coat	Readco Industries, Inc. Ash Street Reading, MA 01867
	B.	Vinyl chips	
	C.	Epoxy glaze coat	
#16	A.	Epoxy base coat	Peterson Chemical Corp. 704 South River Street Sheboygan, WI 53081
	B.	Vinyl chips	
	C.	Urethane glaze	
	D.	Urethane glaze with UV filter	
#17	A.	Epoxy base coat	Peterson Chemical Corp. 704 South River Street Sheboygan, WI 53081
	B.	Granules	
	C.	Urethane glaze	
	D.	Urethane glaze with UV filter	
#18	A.	Epoxy base coat	Acme Chemicals & Insulation Company Div. of Allied Products Corp. P.O. Box 1404 New Haven, CT 06505
	B.	Epoxy intermediate coat	
	C.	Vinyl chips	
	D.	Urethane top coat	
*#19	A.	Epoxy base coat	Mobay Plastics & Coatings Div. Mobay Chemical Corp. Penn Lincoln Parkway West Pittsburgh, PA 15205
	B.	Modified urethane top coat	
#20	A.	Epoxy base coat	General Polymers Corp. 3925 Huston Avenue Cincinnati, OH 45212
	B.	Vinyl chips	
	C.	Sealer coat	
	D.	Epoxy top coat.	

The decorative chips or aggregates used were those supplied by the manufacturer.

The identifications and descriptions of the heating elements are as follows:

Number	Description	Manufacturer
H-1	Conductive nonwoven graphite fabric	Union Carbide Corp. Parma Technical Center P.O. Box 6116 Cleveland, OH 44101

* Available in pilot plant quantities.

H-2	Acrylic conductive paint	Chomerics 77 Dragon Court Woburn, MA 01801
H-3	Epoxy conductive paint	Chomerics 77 Dragon Court Woburn, MA 01801
H-4	Acrylic conductive paint	Hunterlec-USA P.O. Box 53 Markham, VA 22643
H-5	Vinyl-coated heating element	Electric-Heat Company Johnson City, TN 37601
H-6	Copper mesh over vinyl-coated heating cable	Berko Electric Mfg. Corp. Michigan City, IN 46360
*H-7	Polyester-laminated heating element	E.O. DuPont de Nemours 1007 Market Street Wilmington, DE 19898
H-8	Prefabricated metal radiant heating ceiling panel	Berko Electric Mfg. Corp. Michigan City, IN 46360
**H-9	Foil elements in resin-impregnated glass cloth	Cooperheat 3345A Newport Boulevard Newport Beach, CA 92663.

D.2 Performance Tests on Seamless Flooring Systems

D.2.1 Abrasion Resistance. The method for the determination of the abrasion resistance was that described in Method 6192, Fed. Test Method Std. No. 141a. The 20 coating systems were each applied on 4 in x 4 in (100 mm x 100 mm) steel panels with center hole and samples were made in triplicate. For each abrasion resistance determination a load of 1,000 g and abrasive calibrase wheels, No. CS-17, were used with the Taber Abraser. Specimens were abraded for 1000 cycles and the weight loss was recorded to 0.1 mg.

D.2.2 Resistance to Elevated Temperature. The procedure used for the measurement of flow or slip was that described in 4.7.5.1 of MIL-D-3134F. For each of the 20 seamless floorings, the complete system was applied to a steel panel (6 in x 2 in (150 mm x 50 mm)), cured, scribed, and placed vertically in an oven at 158°F (70°C) for 5 hours. The difference between the scribe mark and reference edge before and after heating is a measure of flow or slip. The measurements were taken to 0.0001 in (0.0025 mm).

* Available in pilot plant quantities.
** Designed for use without additional coating.

D.2.3 Impact Resistance. The method for the determination of the impact resistance was that described in ASTM D2794, Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact). Each coating system was applied to a steel panel and the impact tests were performed with the coated side up. The largest impact at which failure did not occur was determined.

D.2.4 Stain Resistance. The method used for the determination of stain release of the seamless flooring was, generally, that described in ASTM D1308, Effect of Household Chemicals on Clear and Pigmented Organic Finishes. Glass rings, 1 in I.D., 1/2 in height (25.4 mm I.D., 12.7 mm) were sealed to the surface with a polyurethane sealer. After curing of the sealer for 24 hours, 1 ml of the stain was placed in the sealed ring and the ring was covered immediately with a watch glass. After 16 hours, the watch glass was removed, the stains were washed off and any alteration to the surface was noted. The following stains were used: detergent, i.e. 5% Ivory Flakes, amyl acetate; acetone; coffee; mustard; tea; Mercurochrome; shoe polish; felt tip marker.

D.2.5 Flammability of Seamless Flooring Systems. The procedure used for the determination of the flammability was, generally, that described in ASTM D635, Flammability of Self-Supporting Plastics. Test specimens were 5 in by 1/2 in (127 mm x 12.7 mm) and were approximately 35 mils in thickness of the seamless flooring system beomg tested. The results were reported as rate of flame spread.

D.2.6 Resistance to Moisture and Elevated Temperature. The procedure for the measurement of resistance to moisture was modified from that described in 4.7.7 of MIL-D-3134F. Each seamless flooring system was applied to a steel panel and the panels were cured for 48 hours. The coated panels were then immersed in distilled water for 48 hours. Immediately after immersion, the panels were exposed to an oven temperature of 158°F (70°C) for 5 hours. The samples were examined for evidence of cracking or other failure.

D.3 Performance Tests on Radiant Panels

D.3.1 Preparation of Radiant Panels. Since the heating elements differed markedly, descriptions for the preparation of the radiant panels (3/4 in x 24 in x 24 in (0.02 m x 0.6 m x 0.6m)) follow:

The conductive fabric (H-1) was furnished as part of a roll. The fabric was spread over the plywood panel and copper strips (10 mil x 2 in x 24 in (0.0025 m x 0.05 m x 0.6m)) were used as electrodes. The copper strips were stapled at opposite ends of the panel. It should be noted that the fabric was extremely fragile.

The conductive paints (H-2, H-3, and H-4) were applied to the plywood panel in accordance with the manufacturer's directions. Copper electrodes, as described previously, were affixed at opposite ends of the panel.

The conductive heating cables (H-5, H-6) were each placed in parallel channels routed in the plywood panel since it was desired to keep the surface as flat as possible. The "S" pattern for the routed channel was approximately 3/16 in (5 mm) deep, 2 in (50 mm) on center and 1 in (25 mm) from the edges of the panel. Aluminum foil 0.001 in (0.025 mm) was used to cover the panel.

The polyester laminated heating element (H-7) of approximately 1/8 in thickness was a self-contained unit consisting of conductive material and aluminum electrodes laminated between 2 layers of plastic. The prefabricated metal heating panel (H-8) had heating cables spaced 2 inches apart underneath the metal skin. This system was fabricated for use on ceilings and was used in this study as a uniform substrate to monitor the performance of the seamless flooring coatings applied to the outer metal skin. The heating panel (H-9) was also prefabricated, but it consisted of a heating element (wire) encased in fiberglass polyester resin.

D.3.2 Surface Temperature Characteristics of the Radiant Panels. The purpose of this test was to produce a panel surface temperature of approximately 80°F (27°C) and to measure the temperature uniformity of the radiant panels both uncoated and coated with the seamless flooring system.

A variable step-down transformer was used to control the applied voltage. A voltmeter and ohmeter were used to measure the applied voltage and the approximate power consumption of the resistive heating circuit.

Surface temperatures were measured by using a digital surface pyrometer and uniformity of temperature was measured by scanning the surface with an infrared television camera. Use of a camera attachment to record the television image afforded a permanent record of the surface temperature uniformity.

D.4 Performance Tests on the Radiant Panel-Seamless Flooring System

After the surface temperature characteristics and power requirements of the nine uncoated radiant panels were obtained, quarters of each of the panels were coated with four of the more promising seamless flooring systems (11b, 17, 19, and 20) applied in 1 sq ft sections. Temperature and power measurements were repeated on the systems.

Based on the overall performance tests, the radiant panel-seamless flooring systems with the heating elements H-2 and H-4 were chosen to be heated continuously for one month at 40 volts. Impact (ASTM D2794), 60° gloss (method 6101, F.T.M.S. No. 141), and color difference (method 6123, F.T.M.S. No. 141) measurements were made on the coatings.

D.5 Performance Tests on a Large Radiant Panel-Seamless Flooring System

The conductive paints (H-2 and H-4) were applied to plywood panels (3/4 in x 48 in x 96 in (0.02 m x 1.2 m x 2.4 m)). Copper strips (10 mil x 2 in x 48 in (0.00254 m x 0.05 m x 1.2 m)) were used as electrodes and were stapled at opposite ends of the panels.

The surface characteristics of the radiant panels were determined as per D.3.2. After the surface temperatures and energy requirements were obtained, the panel coated with the conductive paint H-4 was coated with the seamless flooring system 20. Temperature and power measurements were repeated on the system.

E. RESULTS AND DISCUSSION

E.1 Seamless Flooring Systems

The performance characteristics of the seamless flooring systems are tabulated in table 1 for abrasion and stain resistance, flow, impact resistance, flame resistance, and resistance to moisture and elevated temperatures.

Definite differences in the abrasion resistance of the various systems can be seen in table 1. There were more systems with urethane topcoats (Nos. 2, 4, 11a, 11b, 15, 17, 19) than with epoxy topcoats (Nos. 5, 10, 13, 20) that had a weight loss of less than 0.1 g per 1000 cycles. However, there were more urethane systems under consideration. Also, the decorative chips may have had an effect on the abrasion resistance of the systems tested.

The resistance to flow or slip of all systems was high, with only one system (No. 18) having a movement of as much as 0.006 in (0.0152 mm) under the test exposures.

The impact resistances of the seamless flooring systems were greater than those of the vinyl tiles. However, the urethane systems seemed to have greater impact resistances than the epoxy systems, e.g. most epoxy systems were less than 40 inch pounds (4.5 Nm). The seamless flooring systems were more resistant to stains than vinyl tiles, but acetone and amyl acetate did dissolve most of these materials after 16 hours of exposure.

Test method ASTM D635 was used to test the flame resistance and to screen out the more flammable systems. However, it is not established how well this test relates to flammability of materials in practice.

Generally, all seamless flooring systems were affected adversely during the resistance to moisture and elevated temperature test. This test was judged as too severe since the test was performed at 158°F (70°C) and floor temperatures in actual use would be below 80°F (27°C). This test would have to be modified for it to be used to simulate realistic exposure conditions.

After reviewing the data in table 1 for desired performance characteristics, four systems were selected for use in the radiant panel tests. The selection was based upon arbitrary performance criteria of abrasion resistance less than 0.08 gm weight loss, flow less than 0.0005, impact resistance greater than 40 inch-pounds (4.5 Nm), good stain resistance, flame spread $\leq$2 inches per minute, and resistance to moisture and elevated temperature. The systems were 11b (acrylic base, urethane topcoat), 17 (epoxy base, urethane topcoat), 19 (epoxy base, modified urethane topcoat), and 20 (epoxy base and topcoat).

E.2 Radiant Panel Tests

The radiant panels all produced a very uniform surface temperature as measured both by the digital pyrometer and infrared television camera with the maximum temperature variations being 8°F (4°C). An illustration of the infrared television camera measurements is given in figure 2. The heating elements H-2 and H-4 required less than 40 volts to raise the surface temperature 10°F (6°C) above ambient temperature (see table 2 for system measurements). It should be noted that heating elements H-5 and H-6 were designed to be operated at 110 volts and heating elements H-7 and H-8 were designed to be operated at 230 volts. Also, heating elements H-5 and H-6 were each conductive heating cables placed in a routed channel (3/16 in (5 mm deep)) of the plywood panel, and the different geometry of the system and the aluminum foil covering undoubtedly had some affect on the surface temperatures. Heating systems H-5 and H-6 required 1.6 and 2.1 watts/ft^2 degree C rise, respectively, which was higher than that of any other system. However, the differences in the effectiveness of the heat transfer of these systems is not completely attributable to the different design factors mentioned.

E.3 Radiant Panel-Seamless Flooring System

Application of the four seamless flooring systems to the nine heating systems allowed for a subjective appraisal of the appearance and compatibility of the combined systems. In all cases, there was excellent compatibility or adhesion between the seamless flooring system and heating element. The appearance of the system containing heating element H-1 was irregular due to disruption of the fragile fabric during coating application. This was also reflected in the uneven heat distribution and "hot spots" as seen when heating the combined system. The appearances of the systems containing heating elements H-2, H-3, and H-4 were very uniform. Application of the coating increased the electrical resistance of

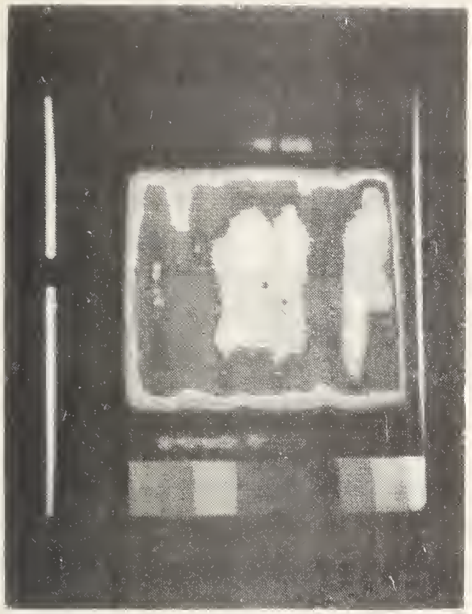
Table 1. Results of Performance Tests of Seamless Flooring Systems

Sample	Abrasion Resistance, Taber wt. loss, g	Flow or Slip inches	Impact Resistance, inch-pounds***	Stain Resistance 5% soap flakes	Amyl Acetate	Acetone	Coffee	Mustard	Tea	Mercurochrome	Shoe Polish	Felt Tip Marker	Flame Spread ASTM D635	Effect of Moisture & Elevated Temperatu
1	0.1571	.0001	28	NE*	dissolves	dissolves	sl. stain	NE	sl. stain	stains	-	-	2 in/min	sl. yellowing
2	0.0981	.0000	>80	NE	dissolves	dissolves	NE	NE	NE	stains	sl. stains	stains	1 in/min	sl. yellowing
3	0.1486	.0001	30	NE	dissolves	dissolves	sl. stain	NE	NE	stains	stains	stains	4 in/min (B)	yellowed
4	0.0704	.0000	80	NE	dissolves	dissolves	NE	NE	NE	stains	-	-	1 in/min	yellowed
5	0.0818	.0001	26	NE	NE	dissolves	NE	NE	NE	stains	-	stains	3 in/min (B)	lost all gloss
6	0.2512	.0000	20	NE	dissolves	dissolves	NE	NE	NE	NE	-	-	2 in/min (B)	cratering in surface increased after imme
7**														
8	0.2572	.0003	80	NE	dissolves	dissolves	stains	NE	sl. stains	sl. stains	-	-	1 1/2 in/min	yellowed
9	0.2614	.0005	50	NE	NE	dissolves	NE	NE	NE	v. sl. stains	-	-	flame extinguished	no change
10	0.0850	.0001	24	NE	NE	NE	NE	NE	NE	stains	-	stains	2 in/min (B)	no change
11a	0.0704	.0002	>80	NE	dissolves	dissolves	NE	NE	NE	stains	sl. stains	-	2 in/min (B)	yellowed
11b	0.0475	.0003	>80	NE	dissolves	dissolves	NE	NE	NE	stains	-	-	2 in/min	sl. yellowing
12	0.1497	.0001	80	NE	NE	dissolves	NE	NE	NE	NE	stains	NE	flame extinguished	sl. yellowing
13	0.0565	.0000	20	NE	NE	NE	NE	NE	NE	stains	NE	NE	1 in/min	extreme yellowing
14	0.3608	.0000	76	NE	dissolves	dissolves	NE	NE	NE	sl. stains	sl. stains	NE	flame extinguished	yellowing
15	0.0996	.0001	80	NE	NE	dissolves	NE	NE	NE	stains	NE	stains	1 in/min	yellowing
16	0.2502	.0000	80	NE	NE	dissolves	sm. blisters	NE	NE	NE	v. sl. stain	v. sl. stain	1 in/min	peeled from substrate no change to material
17	0.0463	.0001	80	NE	NE	dissolves	NE	NE	NE	NE	NE	NE	1 1/2 in/min	yellowed
18	0.1533	.0006	68	NE	softens, lifts	softens, lifts	stains	NE	stain	stain	NE	NE	2 in/min	yellowed
19	0.0625	.0001	80	NE	NE	NE	NE	NE	NE	NE	NE	NE	1/2 in/min	sl. opaqueness
20	0.0308	.0002	40	NE	NE	NE	NE	NE	NE	stains	NE	stains	2 in/min	sl. opaqueness
Vinyl tile			7	NE	softens, dissolves	roughens surface	NE	v.sl. stain	NE	NE	stains	stains		
Vinyl tile			8	NE	dissolves	dissolves	v.sl. stain	sl. stain	NE	v. sl. stain	stains	NE		

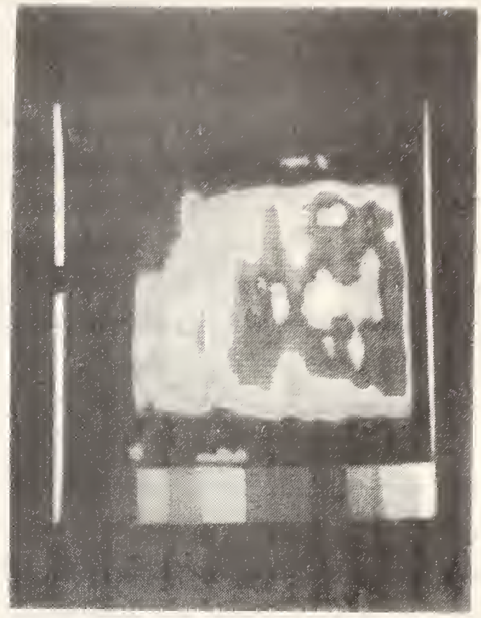
* NE = No effect.

** The initial sample gelled in the container. The replacement was received too late for inclusion in the testing program.

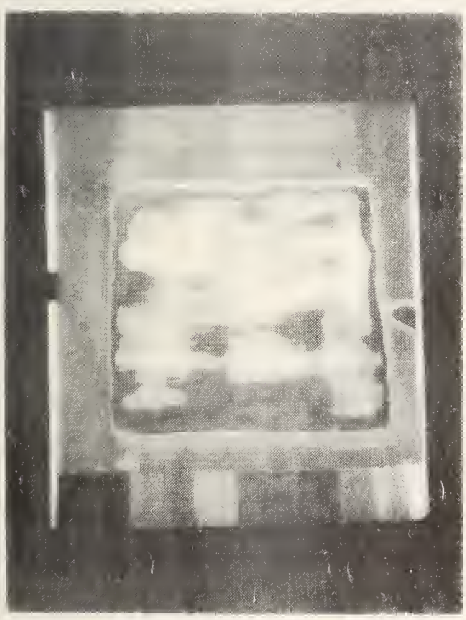
*** Inch-pound-force = 0.113 Nm.



Cold 5°C Range Hot
Heating Element H-2



Cold 5°C Range Hot
Heating Element H-3



Cold 5°C Range Hot
Heating Element H-4

Cold 5°C Range Hot
Heating Element H-6

Figure 2. Infrared television measurements on selected heating panels showing temperature distribution. The temperature scale is shown at the bottom of each.

the system and lowered the surface temperatures for a given applied voltage. The appearance of the systems containing heating elements H-5 and H-6 were not completely uniform as the routed channels for the heating elements were visible. This effect could probably be overcome by the use of heavier gage foil or with thin steel plate. The appearance of the system containing heating element H-7 was also not uniform, and was due to problems in uniformly adhering the heating element to the plywood substrate. It should be noted that this heating system is designed for ceiling application. Heating system H-8 was uniform because of its unitized construction. The appearance of the system containing heating element H-9 was very uniform since the coating systems were applied to a rigid fiberglass-polyester sheet. It would be expected that appropriate modifications to heating elements H-1, H-5, H-6, and H-7 would result in a smooth substrate capable of being coated to a uniform appearance.

The power requirements to raise the panel surface temperatures from about 72°F (22°C) to approximately 80°F (27°C) ranged from about 2 to 6 watts/ft^2 (about 2.2 to about 170 watts/m^2). However, the upper limit observed was for heating element H-1 where local hot spots developed because the uniformity of the nonwoven conductive fabric was disrupted during the coating process. These values are listed in table 2.

The coated panels of heating elements H-2 and H-4 were heated for one month continuously at an applied voltage of 40 volts to determine the stabilities of the systems to prolonged heating. The surface characteristics of the seamless flooring coating systems were examined for changes in 60° gloss, color change, and impact resistance. The results are tabulated in table 3. There is a decrease in impact resistance and noticeable color change in the epoxy (No. 20) and the urethane (No. 11b) systems which could indicate a heat-induced chemical instability while systems Nos. 17 and 19 appeared to be unaffected by the prolonged heating. There was no pattern discerned in the gloss changes for the different coatings; however, the changes in gloss were not considered significant.

E.4 Larger Panel Tests

In addition to the heating tests on the coated panels of heating elements H-2 and H-4, larger panels (3/4 in x 48 in x 96 in (0.02 m x 1.2 m x 2.4 m)) were prepared of the same heating elements (see table 4 for system measurements and figure 3 for infrared television measurements of the systems). System H-2 had a high resistance between electrodes which is not clearly understood. A possible explanation may be chemical interaction between the seamless flooring system and the conductive paint. The larger variation in panel temperature in system H-2 may be explained by problems in the uniformity of the coating application. Since it was not possible to raise the panel temperature of system H-2 to approximately 80°F (27°C) without using higher voltages, seamless flooring was applied only to system H-4. The radiant panel-seamless flooring system was tested for comfort by having the authors walk on the panel in their stocking feet and varying the voltage applied to the panel (see figure 4). Generally, it

Table 2. Results of Heating Tests of Radiant Panels and Radiant Panel-Seamless Flooring Systems

Heating System	Resistance ohms	Voltage V	Watts	Watts/ft^2	Watts/m^2	Ambient Temp.	Heated Temp.	Watts/ft^2 degree C Rise	Watts/m^2 degree C Rise
H-1 (uncoated)	80	40	20	5	53.8	71°F (21.7°C)	83°F (28.3°C)	0.8	8.2
H-1 + seamless flooring	20*	40	80	20	215.8	74°F (23.2°C)	178°F (81.0°C)*	0.3	3.7
H-2 (uncoated	80	40	20	5	53.8	73°F (23°C)	87°F (30.6°C)	0.7	7.1
H-2 + seamless flooring	168	40	9.5	2.3	25.6	73°F (23°C)	84°F (28.9°C)	0.4	4.3
H-3 (uncoated)	320	100	31.3	7.8	84.2	73°F (23°C)	87°F (30.6°C)	1.0	11.1
H-3 + seamless flooring	833	100	12.0	3	32.3	73°F (23°C)	86°F (30.2°C)	0.4	4.5
H-4 (uncoated)	24	40	66.7	16.7	179.4	73°F (23°C)	>100°F (>38°C)	>1.1	>12.0
H-4 + seamless flooring	93	40	17.2	4.3	46.3	73°F (23°C)	89°F (31.7°C)	0.5	5.3
H-5 (uncoated)	115	80	55.6	13.9	149.6	73°F (23°C)	89°F (31.7°C)	1.6	17.2
H-5 + seamless flooring	115	80	55.6	13.9	149.6	72°F (22.2°C)	83°F (28.3°C)	1.6	17.2
H-6 (uncoated)	150	100	66.7	16.7	179.4	73°F (23°C)	88°F (31.1°C)	2.1	22.1
H-6 + seamless flooring	150	100	66.7	16.7	179.4	72°F (22.2°C)	84°F (28.9°C)	2.1	22.1
H-7 (uncoated)	810	100	12.3	3.1	33.1	73°F (23°C)	83°F (28.3°C)	0.6	6.5
H-7 + seamless flooring	910	100	11.0	3.0	29.6	72°F (22.2°C)	83°F (28.3°C)	0.6	5.8
H-8 (uncoated)	300	60	12.0	3.0	32.3	73°F (23°C)	82°F (27.8°C)	0.6	6.7
H-9 + seamless flooring	300	60	12.0	3.0	32.3	72°F (22.2°C)	81°F (27.4°C)	0.6	6.2
H-9 (uncoated)	18	12	8.0	2.0	21.5	68°F (20°C)	80°F (26.7°C)	0.3	3.2
H-9 + seamless flooring	18	12	8.0	2.0	21.5	68°F (20°C)	82°F (27.8°C)	0.3	2.7

* Application of seamless coating caused the fabric to be displaced and local hot spots occurred. The temperature listed was the maximum observed.

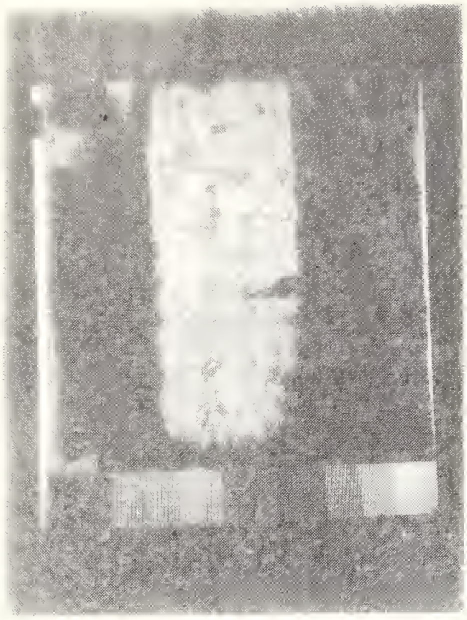
Table 3. Surface Characteristics of Radiant Panel-Seamless Flooring Systems (Nos. 2 and 4) after Heat Stability Test (1 month, 40V)

Heating System	Coating System	Change in 60° Gloss	Change in Color, ΔE	Impact Resistance inch-pounds* Before	After
H-2	11b	+4.0	6.1	80	18
	17	-5.4	.6	80	80
	19	+3.2	.7	80	80
	20	-9.7	1.5	40	6
H-4	11b	-2.6	4.7	80	20
	17	+3.8	.6	80	80
	19	+3.3	.4	80	80
	20	+5.2	2.6	40	4

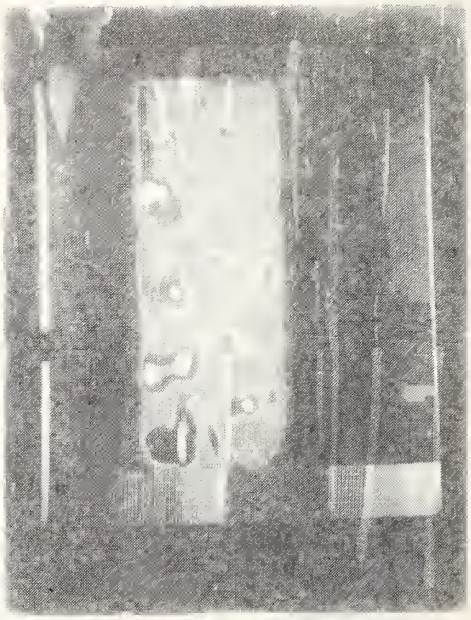
* Inch-pound-force = 0.113 Nm.

Table 4. Results of Heating Tests of Radiant Panels (0.02 m x 1.2 m x 2.4 m) and Radiant Panel-Seamless Flooring System

Heating System	Resistance ohms	Voltage V	Watts/ft^2	Watts/m^2	Ambient Temp.	Heated Temp.	Watts/ft^2 degree C Rise	Watts/m^2 degree C Ris
H-2	220	20	.1	1.2	69°F (20.8°C)	70°F (21.0°C)	.5	5.4
		40	.2	2.4	69°F (20.8°C)	72°F (22.0°C)	.4	4.3
		60	.5	5.5	69°F (20.8°C)	74°F (23.6°C)	.4	4.3
H-4	30	20	.4	4.5	69°F (20.8°C)	72°F (22.1°C)	.3	3.5
		30	.9	10.1	69°F (20.8°C)	76°F (24.4°C)	.3	2.8
		40	1.6	17.9	69°F (20.8°C)	78°F (25.4°C)	.4	3.9
		50	2.6	28.0	69°F (20.8°C)	81°F (27.1°C)	.4	4.4
H-4 + seamless flooring	55	40	.9	9.8	72°F (22.3°C)	78°F (25.5°C)	.3	3.1
		50	1.4	15.3	72°F (22.3°C)	79°F (26.3°C)	.3	3.8



Cold 1°C Range 60 Volts Hot



Cold 10°C Range 40 Volts Hot

Figure 3. Infrared television measurements on large panels showing temperature distribution. The temperature scale is shown at the bottom of each.

Figure 4. Large Radiant Panel-Seamless Flooring System

was comfortable when the surface temperature was less than 90°F (32°C). The variability in resistance and surface temperature in these moderate scale-up tests illustrates the necessity for uniform film application and good electrical connections.

E.5 Cost Effectiveness of Radiant Panel-Seamless Flooring System

Since the heating elements in the radiant panel-seamless flooring system are of the resistive heating type, and assuming an efficiency of 1.0, the cost of electricity delivered to the conditioned space area is $.88/therm or approximately twice that of gas ($.40/therm) or oil ($.47/therm) [12]. These costs are typical in the Washington, D.C. area at the present time. Savings in electrical consumption are possible by heating only occupied living areas and by utilizing the quick response heating characteristics of the system. A potential use of the system would be in a retrofitting process where it would supplement an inadequate existing heating system. The low thermal lag time for heating might possibly result in lower energy consumption by a reduction in physiological needs for heating by an occupant. Clinical studies, involving occupants in residential housing, should be made to validate this premise. Also, comparison should be made between room-controlled electrical heating units, which generally are at the room perimeter, and the radiant panel-seamless flooring system to determine any differences in energy consumption and physiological needs.

The installation and maintenance costs of the radiant panel-seamless flooring system which uses conductive paints as the heating element appear to be attractive, especially in a retrofitting process. Installation costs of the heating elements would require connections to the house electric power and each area to be heated would probably require a ground fault circuit interrupter for safety purposes and these costs of installation would be similar for all systems. Installation costs of the conductive paints should be comparable to that of interior paints which have an estimated installation cost of $.10-.17/ft^2 [13]. The installation cost of the conductive paints would be approximately half the cost of the polyester-laminated heating element [14] and much less than the cost of heating cable installation [13]. Installation costs for the seamless flooring systems are comparable to other flooring systems, e.g. vinyl tiles, wood, and less than carpeting [13]. These seamless coatings are considered durable and relatively easy to repair.

The conductive paints were compatible with the seamless flooring systems. They could be considered encapulated into the seamless flooring systems. Thus, the durability and maintenance of a conductive paint would be similar to that of the seamless flooring rather than as an interior paint. The longevity of the seamless flooring conductive paint heating element system may be estimated at approximately 10 years, but the effects of long term heating on the radiant panel-seamless flooring system needs evaluation before a judgment on life cycle costing can be made. Repair of heating elements just beneath the seamless flooring should be less costly than the repair of radiant heating elements embedded in concrete. The power requirements for conductive paints used as heating elements are relatively low; they were determined to be 3.1 to 5.3 watts/m^2·degree C rise. However, the cost effectiveness is dependent on the possible reduction in ambient temperatures and this is dependent on the results of longer term physiological testing such as the effects of floor temperatures on comfort.

F. SUMMARY

The following items summarize the general conclusions of this feasibility study:

- The radiant panel-seamless flooring system studied appear to be feasible for use as quick response heating systems; however, larger scale, longer time tests would be needed before implementing their use.

- The resistance of twenty seamless flooring systems to abrasion, flow, impact, flame, stain, moisture and elevated temperature were evaluated using laboratory tests. These results can be used to develop performance criteria on which to base the selection of seamless flooring systems.

- Performance tests on the seamless flooring systems indicated differences in performance related to generic type, e.g. systems with urethane topcoats generally rated higher in the initial performance tests.

- Power requirements and the magnitude and uniformity of surface temperatures of nine electrical heating elements, functioning as radiant heating panels, were experimentally determined and evaluated. Overall, the conductive paints appeared to have the most promise as a heating element in a radiant panel-seamless flooring system. While the other heating elements were not designed specifically for floors nor for use at low voltages, it appeared that they could be adapted to function effectively in a radiant panel-seamless flooring system.

- A number of heating elements had sufficiently low electrical resistances so that it is estimated that they could be used or modified to obtain voltage drops less than 50 volts with electrodes placed 10 feet apart; this should allow for supplemental heating in most rooms. However, NEC only approves electrical radiant heaters buried six inches in a concrete slab for floor radiant heating installations. The use of safety devices such as ground fault circuit interrupters and low voltages might provide a basis for acceptance of this type heating system by NEC. (See Appendix A for the identification of future areas for work.)

- Power consumption of the systems ranged from about 2 to about 16 watts/ft^2 (about 22 to about 170 watts/m^2) to heat the test panels approximately 10°F (5°C) above ambient temperature.

- The effectiveness of producing radiant energy by the heating elements appears to be dependent on the geometry of the system, i.e., heating elements on top of the plywood panel and directly underneath the seamless flooring were more effective than heating elements embedded in the plywood panels.

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APPENDIX A - Identification of Areas for Future Work

Radiant heating in seamless flooring appears to be a feasible concept, but research and development will be required before the system can be adapted for general usage. These include:

- The National Electric Code (NEC) would have to be modified to permit use of radiant panel-seamless flooring system. Extensive safety testing would be necessary prior to usage in family-occupied public housing units.

- The effectiveness of radiant heating is directly related to the physiological effect on an occupant. For example, with radiant heating, little or no air motion occurs, the heat is concentrated on the feet, and comfort is achieved at lower ambient temperatures. Thus, extensive clinical studies would be desirable to evaluate the effectiveness of this type of heating.

- To demonstrate the merits of the radiant panel-seamless flooring system, the following information would need to be integrated into a cost effectiveness study: power consumption, safety costs, installation and maintenance costs, and the results of clinical testing of occupant physiological responses.

- Field testing of the system should be initiated as soon as possible. Where code limitations would not affect the field tests, flooring areas in selected buildings should provide a controlled environment for the initial demonstration tests.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The purpose of this study was to determine the feasibility of using radiant heating in seamless flooring as a supplemental heating source in housing units. The resistance of twenty seamless flooring systems to abrasion, flow, impact, flame, stain, moisture and elevated temperature were evaluated using laboratory tests. Power requirements and the magnitude and uniformity of surface temperatures of nine electrical heating elements, functioning as radiant heating panels, were experimentally determined and evaluated. The radiant heating panels were coated with selected seamless flooring systems and the performance characteristics of the radiant panel-seamless flooring system were evaluated. The report contains a summary of test results demonstrating the feasibility of the radiant panel-seamless flooring system and the identification of areas for future research.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Electrical heating elements; materials performance; radiant panel-seamless flooring system; seamless flooring; temperature characteristics.

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