# IMPROVING LOCAL THERMAL COMFORT IN BUILDINGS: A STUDY OF PROPERTIES OF HEATING TEXTILE COMPOSITES IN CONSTRUCTION INDUSTRY

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**ABSTRACT**

The focus of this study is to analyze heating and insulating properties of textiles utilized in the construction industry. Research regarding textile heating composites typically centers around their use in the fashion industry and personal thermal comfort. Therefore, the study focuses on the application of textile heating composites as a method for improving the local thermal comfort of the user. The aim of this project was to analyze and describe the heating and insulating properties of electroconductive yarns and insulating textiles used in the construction industry. This goal was achieved by building physical samples that underwent heating tests. The next step was to compare the examined properties and select the best combination of yarn and fabric, which was then tested in the target environment. It was concluded that the best heating results are achieved with steel thread embroidered on fiberglass mesh and combined with extruded polystyrene that can be used to improve the local thermal comfort of the user.

**KEYWORDS**

Electroconductive yarns; Heating; Embroidery; Personal thermal comfort; Composite; Building.

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## INTRODUCTION

The search for new materials with better and better properties has led to the creation of a new group of materials known as composite materials. When designing innovative composite materials, they consider the operating conditions and the loads under which they will work. The rapidly growing industry related to the production of composite combines issues in the field of textiles, metallurgy, mechanics and chemistry of polymers, and plastics processing. [4]

A special field of composites is the combination of textiles and electronics, known as textronics. Programmable products can be produced through technical embroidery, weaving, or wreathing, and thanks to the use of flat textile products, they are flexible and portable. Popular applications of textronics are actively heating clothes or garments that measure basic life parameters. [1], [8], [10].

Heating textile composites have been described and tested mainly in the application of the fashion industry and personal thermal comfort products. [2], [9] For building heating usually used are classic heating systems with radiators connected directly to the power plant or to local water heating systems. [5], [7] Floor heating is used less frequently, usually in combination with one of the aforementioned heating methods, as an additional element increasing the local thermal comfort of the user. [11]

Thermal comfort is a mental state in which a person subjectively feels a sense of warmth. It depends on two kinds of factors:

- Thermal conditions, including air temperature, humidity, air movement, and radiant temperature, e.g., cool air near a window.
- Workers' individual personal factors, such as level of physical activity and clothing. Physical factors such as weight, gender, and age are also important variables. [6]

## EXPERIMENTAL

### Materials and fabrication procedures

A steel thread with a nominal electrical resistance of 27Ω per meter, a silvered thread with a nominal electrical resistance of 80Ω per meter, and a carbon rowing of unknown nominal electrical resistance were used to create a technical embroidery on a fiberglass mesh of 330g/m$^2$ density and 30mm thick extruded polystyrene was used as insulation material, covered with 5mm thick expanded polystyrene with an aluminum layer on top (Figure 1C). The polystyrene was combined with a designated glue, and the fiberglass mesh with the embroidery was then placed on top of it (Figure 1B) using heat-resistant and nonconducting glue. All fitting packet was cowered by Jacquard woven fabric. (Figure 1A) The first samples were made with a single thread as shown in Figure 2, in a shape of a square with 50 cm long sides and 1 cm distance between single lines for steel and silvered threads. The pattern was adjusted accordingly for the carbon rowing with 2 cm distance between the lines. Next samples were made with multiple threads, as shown in Figure 3, also in a shape of a square and 1 cm distance between single lines for steel and silvered threads, but with 30 cm long sides. The pattern was adjusted accordingly for the carbon roving with 1,5 cm distance between the lines. In samples made with the pattern from Figure 2, the ends were connected directly to the energy source, while in samples made with the pattern from Figure 3, the ends were connected to form a parallel circuit, and then connected to the power source. Samples were then covered with a layer of jacquard woven fabrics made by Marta Rzeźniczak (Institute of Architecture of Textile, Lodz University of Technology).

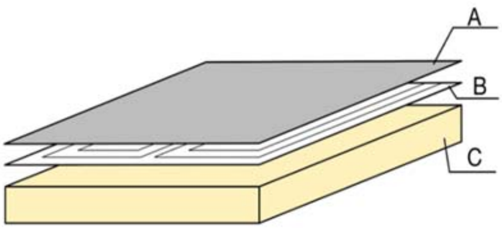


**Figure 1.** Schematics of samples. A – Jacquard woven fabric, B – heating embroidery on fiberglass mesh, C – extruded polystyrene.

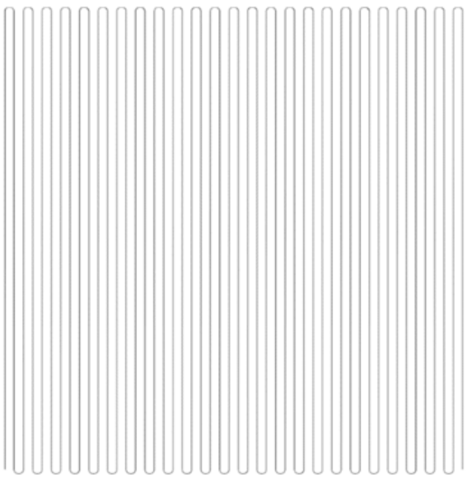

**Figure 2.** Pattern used to make first samples.

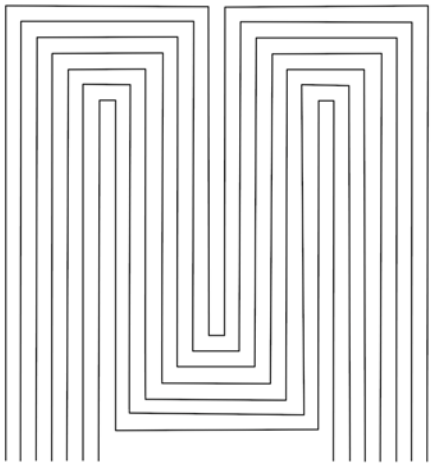

**Figure 3.** Pattern used to make second samples

## Experimental procedures

First samples were tested to measure the electric resistance and the minimum voltage needed for a heating effect. Then after adjusting the pattern, samples were made in different configurations: 1) steel thread embroidered on fiberglass mesh, 2) embroidery on fiberglass mesh attached to polystyrene, 3) embroidery on fiberglass mesh attached to polystyrene and covered with the jacquard. Corresponding samples were made using carbon fiber. The samples were then connected individually to a DC power source with an effective voltage of 22V and were investigated under thermal camera ThermaCAM E65 for maximal temperature, the time needed to reach maximal temperature, and the time needed for cooling down to a temperature of 24°C. The temperature of the environment was 21,2°C. Then the steel thread sample covered with jacquard was tested for current-voltage characteristics and temperature as a function of voltage using the same DC source as before. The active power of the system was calculated using the current-voltage characteristic. The sample was also tested for heat conduction coefficient to see whether the embroidery and jacquard influenced the declared coefficient of extruded polystyrene (XPS).

## RESULTS AND DISCUSSION

## Minimal voltage

The samples were tested for approximate electric resistance to estimate the minimum voltage needed for the heating effect. The results were as follows: steel thread – 550Ω, carbon fiber - 640Ω, slivered thread - 3300Ω. Because of the significantly bigger resistance of the silvered thread, it was eliminated from further research as ineffective. The minimum voltage needed for the heating effect oscillated between 240V-300V. To reduce voltage to safe quantities, the pattern was adjusted to accommodate shorter lengths of threads and parallel circuits.

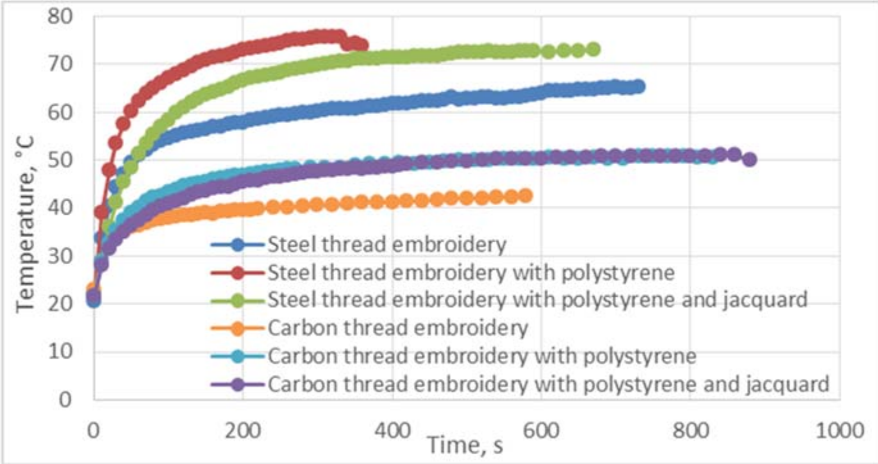


**Figure 4.** Comparison of temperatures and heating times of different samples.

**Table 1.** Results of observation under a thermal camera.

| Lp | Sample | Maximal reached temperature, °C | Heating time, s | Cooling time, s |
|---|---|---|---|---|
| 1 | Steel thread embroidery | 65,3 | 740 | 240 |
| 2 | Steel thread embroidery with polystyrene | 75,7 | 360 | 679 |
| 3 | Steel thread embroidery with polystyrene and jacquard | 72,9 | 670 | 943 |
| 4 | Carbon thread embroidery | 42,4 | 580 | 191 |
| 5 | Carbon thread embroidery with polystyrene | 50,9 | 830 | 567 |
| 6 | Carbon thread embroidery with polystyrene and jacquard | 51 | 880 | 732 |

## Thermal camera observation

Samples made with the adjusted pattern were observed under a thermal camera, as shown in Figure 4 and Table 1. The best results were achieved with steel thread covered with jacquard woven fabric. Despite longer heating time than just extruded polystyrene with steel thread embroidery on fiberglass mesh, it achieves a similar temperature and is more user-friendly – the electroconductive threads are covered, so there is no danger of accidental burn or short circuit. The carbon rowing heated up to lower temperatures needed more time to reach maximum temperature and cooled down faster. Overall, steel thread performed better, with shorter times of heating up and longer times of cooldown. The jacquard cover didn't have a big impact on the maximum temperature, slightly changing the heating curve in comparison to just the embroidery and polystyrene combination (Figure 4).

## Steel thread sample with jacquard woven fabric covering

After comparing results from previous tests, it was concluded that further research will be conducted on a sample made with steel thread with the jacquard covering. As shown in Figure 5, the maximal measured temperature within safe for humans voltages was 93°C. Apart from the initial heating voltage between 0V and 10V, the dependence between voltage and temperature is linear (Figure 6). It may prove to be useful in further research and developing control systems. The current-voltage characteristic on Figure 5. demonstrates that there are no statistically important differences in resistance due to heating. It was used to calculate the active power of the sample, as shown in Table 2. Comparing it with the power needed to heat a square meter of a room [3] it may be concluded that there should not be a significant difference between the energy efficiency of radiators and the presented composite.

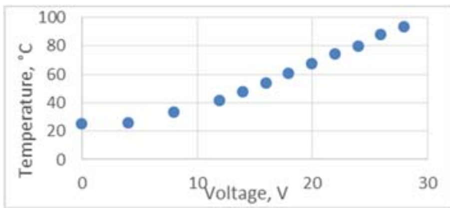


**Figure 5.** Temperature as a function of voltage for steel thread embroidery on fiberglass mesh with XPS and jacquard woven fabric.

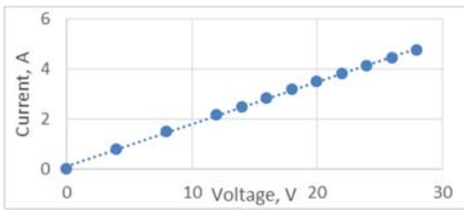


**Figure 6.** Current-voltage characteristic for steel thread embroidery on fiberglass mesh with XPS and jacquard woven fabric cover.

**Table 2.** Active power as function of time.

| Temperature °C | 25,8 | 32,8 | 41,5 | 47,5 | 53,8 | 60,6 | 67 | 74,2 | 79,5 | 87,5 | 93 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Active power W** | 3,04 | 11,89 | 25,97 | 34,4 | 45,12 | 57,02 | 70,04 | 83,6 | 98,88 | 114,92 | 132,16 |

## CONCLUSIONS

The presented study showcased the heating potential and characteristics of different electro-conductive threads. The samples were made using steel thread, silvered thread, and carbon roving, which were embroidered on fiberglass mesh. Then they were glued on extruded polystyrene and covered with jacquard woven fabric. Their electric resistance, heating potential and time, cooling time, and temperature as a function of voltage were measured. Current-voltage characteristic was made and used to calculate the active power of the sample. The main results are summarized below:

1. After comparing electric resistance and maximal temperatures reached by different threads, the steel thread was chosen as the overall best material for heating purposes.
2. There is no statistically significant difference between the performances of the sample on extruded polystyrene with the jacquard woven fabric cover and the one without the cover.
3. The studied composite has comparable active power to those of typical radiators, therefore being an equally energy-efficient source of heating.

Considering all the above, it can be concluded, that textile composites are a good mode of improving local thermal comfort.

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