

Chapter 18

Smart Printed Paperboard for Green Infrastructure



T. K. S. LakshmiPriya  and N. Alagusundari 

Abstract The living infrastructure, consisting of both the natural and man-made infrastructure constituting the green infrastructure, is undergoing serious imbalances, thereby affecting the ecological balance. Drastic ecological balance is a threat to the human existence on earth. Presently, awareness of this threat and the need to save the earth are being felt at large. Initiatives around the globe are underway to protect the earth from all disciplines and communities across nations. Green buildings and green roof with temperature control measures play a key role in green infrastructure. However, the use of thermocol is a widely prevalent, irreplaceable lining for air-conditioned halls. Thermocol is manufactured from polystyrene, a petroleum-based plastic, and its incineration emits toxic gases causing damage to the environment. Our work presented in this paper deals with an alternative eco-friendly solution to this issue. Our work deals with a paperboard-based material as an alternative to thermocol, and the use of printed electronic components embedded within these boards acts as temperature control mechanisms in a green building. As a proof of concept, a prototype printed circuit has been prepared and embedded in a one-inch multi-ply recycled paperboard.

Keywords Paperboard walls · Smart infrastructure · Printed electronics

18.1 Introduction

Green infrastructure refers to the range of practices that restores some of the natural processes required for a sustainable, healthy environment, and also contributing to a better social and economic society. Green infrastructure, also known as ‘low-carbon

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infrastructure,' is a major solution to restore the imbalance in nature caused by modernization and man-made infrastructure.

Green infrastructure can be understood as a process of protecting and enhancing nature and natural process. The green infrastructure is a strategically planned network of nature and semi-natural areas. These practices include rain gardens, vegetable swales, green roof, and porous pavements. Green infrastructure and green roof will absorb less amount of heat and will have cooling effects which can be controlled by sensors.

Green infrastructure is also considered as the basic building blocks of smart cities which facilitate good urban planning methods with the help of either digital technology and/or reengineered old concepts. Green infrastructures have anthropocentric functionalities. One of the functions is to maintain the temperature of buildings at moderate levels using approaches environment friendly or in a low-carbon mode. Such a facility is supposed to contribute to three benefits: (i) a better human health, (ii) reduction in costs for maintaining the temperature, and (iii) provide a sustainable environment.

In this paper, one such approach is presented. Green infrastructure is made a reality in this work, by employing a recycled paperboard as the interior walls and ceiling of a temperature-controlled enclosure. This infrastructure has inherent thermal insulation properties, and hence, the duty cycle of temperature control mechanisms such as air-conditioners will lead to lower carbon footprint. Secondly, an Internet of things (IoT) approach is adopted to monitor and control the temperature. This IoT system is built using the printed electronics technology, thereby becoming an integral part of the paperboard infrastructure.

The rest of the paper is organized as follows. Section 18.2 reviews the literature for the concepts adopted in this work. In Sect. 18.3, the novel idea of integrating printed electronics technology with recycled paperboards to prepare green infrastructure is described. The work in progress is elaborated in Sect. 18.4, and the paper concludes in Sect. 18.5.

18.2 Literature Survey

This section gives a short insight into the applications of paperboards and printed electronics, specifically in the building construction sector.

18.2.1 *Recycled Paperboards as Interiors for Buildings*

For over a decade, paperboard tubes have been in use in structural and construction engineering [1]. Some of the earlier works by one of the authors deal with the preparation of handmade paperboards with water hyacinth fibers as ingredients. It

has been found that such boards have thermal insulation property apart from being eco-friendly. These boards are potential candidates for green infrastructure.

Multiple plies of water hyacinth-based recycled paperboards were formed into a one-inch thick slab to test the feasibility of its usage as construction material. Alternately, due to thermal insulation property, these boards can be used as liners for inner walls and ceiling of enclosures that are air-conditioned.

From the eco-friendly perspective, the authors note that the use of water hyacinth in paperboards is a reduction-by-elimination approach to do away with water hyacinth which is a menace to corporations and municipality who are responsible for the maintenance of water bodies [2–4].

18.2.2 Printed Green Infrastructure

The last decade has witnessed the success of innovative application areas for printed electronics, and green infrastructure is one of them. Some of the research works, relevant to the contribution of this paper, are presented here.

Fernandes et al. have developed an algorithm to control the luminance level of split-pane electrochromic windows [5] that operate like Venetian blinds, so as to achieve better lighting energy saving. Such windows not only provide the inmates of the rooms with an unobstructed view of the outside but also saves 30–40% of lighting energy, thereby contributing to a greener infrastructure.

Building integrated photovoltaics (BIPV) refers to photovoltaic materials (solar cells) that are mounted on building materials used in roofing or wall systems. These servers dual purpose: building coverage and a source for electric power generation. This energy harvesting approach requires not additional cooling system as it becomes an integral part of the concrete in the walls. In his work, Jelle reviews the development and application of BIPV [6].

Hancke and Silva discuss the role of sensors that help in monitoring and controlling operations in smart cities [7]. The authors emphasize the significance of sensors in this domain with numerous applications and also discuss the challenges.

The increasing use of electronics into building infrastructure has attracted the printed electronics researchers to explore the use of printed components for building infrastructure. The National Research Council of Canada has identified printed electronics as a key enabling platform technology for smart infrastructure and cities of the future. Building integrated organic photovoltaic cells (BIOPVs) have been integrated in concrete façade elements, which form the building blocks for constructing green buildings [8].

Thus, it is evident that the growing need for green infrastructure and smart cities calls for the use of sensor-based infrastructure, which is now moving toward thin films and printed sensors. In this paper, we present a case where recycled paper boards can house printed electronic components for control operations in a smart building for energy-saving purposes.

18.3 Proposed Smart Printed Paperboard

Over the years, the use of air-conditioners for maintaining lower indoor temperatures has increased significantly. The hydro-fluoro-carbon (HFC) in air-conditioners is a greenhouse gas (GHG) and contributes to global warming. The carbon footprint of air-conditioners ranges from 300 kg CO₂ per year to over many thousands, depending on the capacity and application [9].

Recently, conscious efforts are being taken to minimize the use of GHGs. The proposed work in this paper is one such effort. This work has two contributions—(i) the use of multi-ply paperboard-based lining material as a replacement for thermocol for thermal insulation in buildings and (ii) the use of printed electronic circuits embedded in these linings, to regulate the air-conditioners. This is illustrated in Fig. 18.1.

Thermocol is manufactured from polystyrene, a petroleum-based plastic, and its incineration emits toxic gases. Paperboards, on the other hand, are eco-friendly. The carbon footprint of paperboard production (for 1000 kg of books) is about 1093 kg CO₂ [10]. Some of the earlier works of the author indicate that paperboards have thermal insulation property and hence are potential substitutes for thermocol for lining air-conditioned enclosures [2]. Hence, the use of multi-ply paperboard-based slabs can become an eco-friendly element for green infrastructure.

Secondly, the use of thin film technology and printed electronics, in making these paperboard-based slabs into walls smart, will further enhance the functionalities and capabilities of green infrastructure.

The primary advantage of the proposed system is that the carbon footprint is significant only during the manufacturing process and neither during usage nor during disposal.

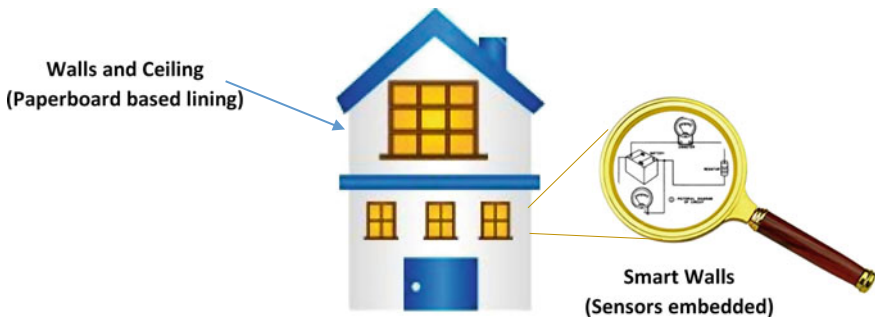


Fig. 18.1 Environment of operation

18.3.1 Methodology

The stages involved in the setting-up of a smart printed paperboard-based green infrastructure are shown in Fig. 18.2.

The production cycle begins with obtaining the specifications of the enclosure that needs temperature control, i.e., the room to be fitted with air-conditioner. The size of the enclosure, preferred temperature, tolerances on temperature variation, air-conditioner type, and carbon footprint, etc., are some of the essential parameters.

Using the data collected above, the specification of the temperature regulator mechanism is determined, i.e., the thickness of the paperboard lining, number of layers in the lining, ingredients of the paperboard.

The subsequent stages are concerned with the manufacture of the proposed lining for walls and ceilings, namely (i) preparation of the paperboard layer, (ii) preparation of a smart layer, and (iii) preparation of a multi-layer (or multi-ply) lining. The final stage is the testing product for correct operation and quality.

18.3.2 Manufacture of Paperboard Layer

Paperboard is prepared from waste paper and other ingredients such as cotton waste, water hyacinth fibers, sisal fibers, or kitchen waste. The manufacturing process flow is depicted in Fig. 18.3.

Paper waste is shredded or split and soaked for about 5 h or more depending on the coating and GSM of paper. If agriculture waste or kitchen waste are used, they also soaked along with paper. The mixture is then put in a beater for pulping during which additives are added to enhance mechanical and printable properties of the paper. This pulp is then sieved and hard pressed for the formation of paper base. The paper base is dried on a flat surface and then calendered for a glossy surface. The

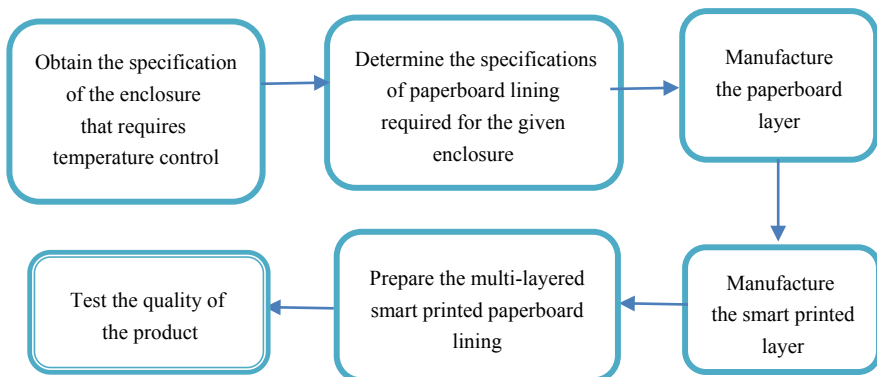


Fig. 18.2 Production cycle of smart printed paperboard

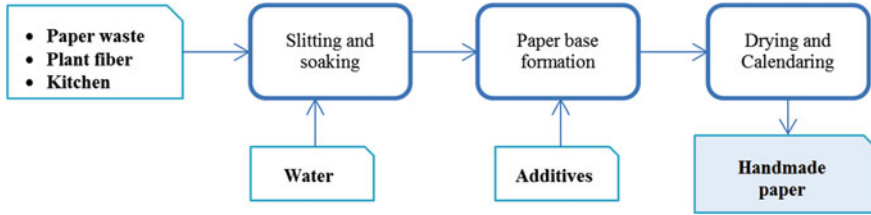


Fig. 18.3 Paperboard manufacturing process

paperboard thickness can be varied as per the requirement, by controlling the pulp quality while sieving the pulp to form the paper base.

18.3.3 Manufacturing the Smart Printed Layer

The process of manufacturing the smart printed layer is illustrated in Fig. 18.4.

- The process begins with gathering the requirements for the manufacture of the smart printed layer. The dimensions of the enclosure, its temperature requirements, normal operating temperature range, unacceptable temperature range, and temperature control requirements are some of the parameters that contribute to the design of the smart control circuit.
- The specifications collected in the previous stage are used to design the temperature control circuit. Care is taken to keep the power consumption at the minimum. The ratings of the circuit elements are finalized, and the circuit is drawn to suit the needs

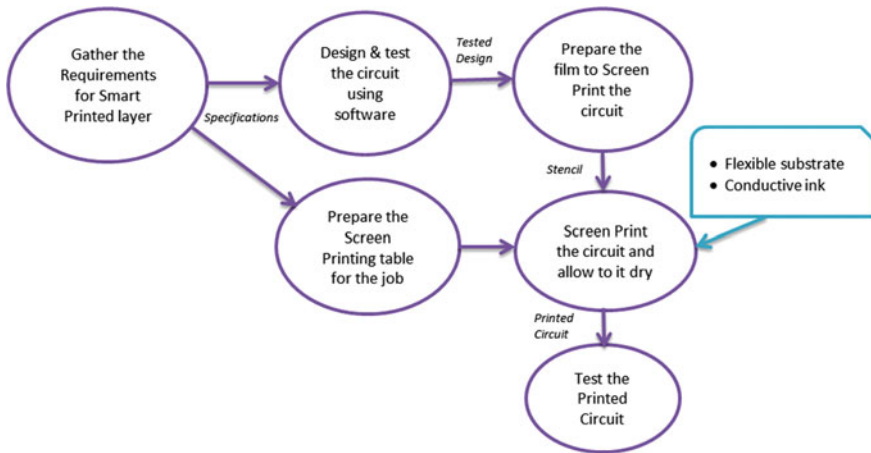


Fig. 18.4 Process of preparing the smart printed layer

of screen printing process. The thickness of the conducting lines and crossing overs is the key factors. The simulated circuit is tested.

- The vector image of the circuit design is generated and used for preparing the film, which is the image carrier for screen printing.
- Meanwhile, the table for the screen printing process is prepared with the required substrate and ink.
- The circuit is screen printed on the CT5 film substrate using conductive ink. Care is taken to maintain high resolution and consistency in the print, to ensure uniform conductivity. The print is allowed to dry and heated if required. The circuit elements are connected to the conductive lines, and the external power supply is connected.
- The screen printed circuit is tested for accurate functioning.

18.4 Work in Progress

As a proof of concept, a prototype printed circuit has been prepared and embedded in a one-inch multi-ply recycled paperboard. The details of these are presented below.

18.4.1 Multi-ply Paperboard

Paperboards were prepared using the waste papers and used record sheets of the students in our campus. The recycling was done in the recycling unit attached to the Department of Printing Technology. Many layers of paperboards are made and its been glued into a single board-ply. These are illustrated in Fig. 18.5.



Fig. 18.5 a Slitting and soaking. b Paper base formation. c Paperboards

18.4.2 Smart Printed Layer

The circuit for the smart printed layer consists of a thermal sensor for data acquisition and LEDs for status display. The design was carried out on Proteus 8.0 which is an electrical suite for circuit design and simulation. The smart layer is a SMT-type flexible circuit, and hence, provisions were provided in the PCB layout for placing the components. The evaluations and testing of the circuit were made on the simulator.

The tested circuit was redrawn on a CorelDRAW, vector graphic software, to fit into $1\frac{3}{4}'' \times 3''$ layout. The circuit was printed on a chromo film and exposed in a UV unit, and the screen stencil was ready.

The circuit was screen printed on the CT-5 film using conductive ink and allowed to dry at 60°C for 2 h. The circuit thus printed was tested for conductivity, wherein the conductivity between various segments of the circuit was tested using a multi-meter. It is essential to have uniform conductivity throughout the circuit for the proper functioning of the circuit.

The next stage was the placement of components—namely, the temperature sensor (LM35), LED (SMD), resistors ($1\text{--}10\text{ K}\Omega$), transistor (BC847)—following which an external power supply (5 V) is crimped to the printed circuit.

The completed circuit was tested for proper functioning and performance. These steps are depicted in Fig. 18.6a–f.

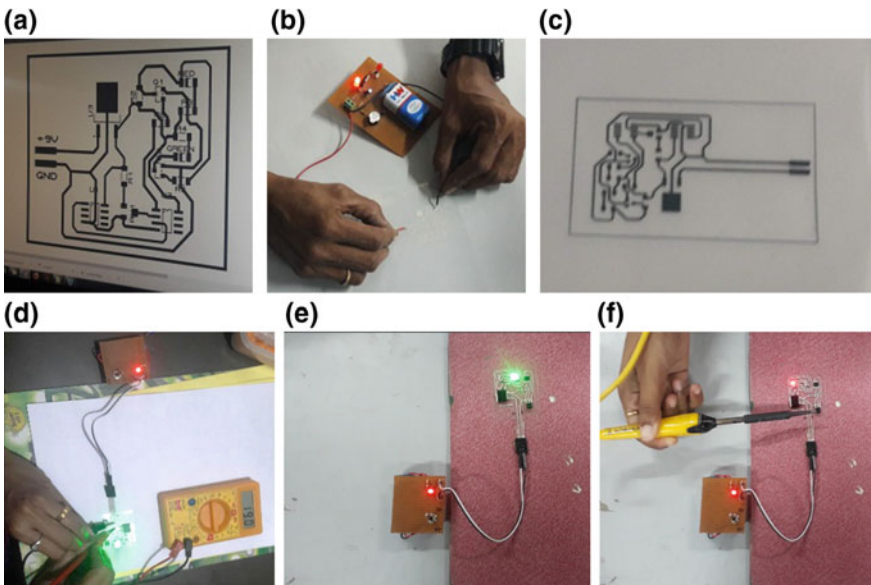


Fig. 18.6 a Design on Proteus. b Preliminary testing. c Printed circuit. d Conductivity test. e Normal temperature: green LED glows. f Temperature rises above threshold: red LED glows

Table 18.1 Measured average width of the conductive line

| Point of measurement | Width (mm) |
|--------------------------------------|------------|
| Outer vertical line (left) | 0.43 |
| Outer horizontal line (top) | 0.40 |
| Inner vertical line (near sensor) | 0.41 |
| Inner horizontal line (near red LED) | 0.43 |
| Inner horizontal line (near LM258) | 0.41 |
| Average width | 0.416 |

Table 18.2 Measured characteristics of the prototype

| Description | Value |
|--------------------------------------|---------------|
| Size of printed circuit | 40 mm × 70 mm |
| Average width of the conductive line | 0.416 mm |
| Standard deviation in width | 0.012 mm |
| Voltage drop | 10 mV |

18.5 Result and Discussion

The circuit designed and printed was first checked for correctness which is done by checking the compliance of the dimensions with the expected specifications, the width of the printed lines, the placement of the components and by carrying out the conductivity. The readings are tabulated in Table 18.1.

The average width of the circuit is 0.416 mm with a standard deviation of 0.012 mm which is acceptable for a prototype done on a low-cost basis.

The characteristics of the circuit are given in Table 18.2. These values are sufficient for a working prototype to serve as a proof of concept. However, the circuit has to be tested for stretchability of the substrate, performance of the circuit with varying deviation width, failure conditions, etc.

18.6 Conclusion

Paperboards have significantly low carbon footprint as compared to thermocol. Hence in this work, paperboards have been prepared to serve the purpose of linings for air-conditioned rooms. Secondly, for moving toward green infrastructure, these linings have been embedded with a smart layer, namely the smart printed layer which comprises printed circuit for monitoring the temperature of the enclosure. Thus, this paper presents a new avenue for incorporating components in a green infrastructure.

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