



ENHANCING ENERGY EFFICIENCY IN PRINTING DRYERS USING LEAN PRINCIPLES: A CASE STUDY

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Open Access Research Journal of Engineering and Technology, 2026, 11(01), 099–109

Publication history: Received on 15 August 2026; revised on 20 September 2026; accepted on 22 September 2026

Article DOI: <https://doi.org/10.53022/oarjet.2026.11.1.0068>

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ABSTRACT

This paper presents a practical lean improvement initiative aimed at reducing energy consumption and CO₂ emissions in the Heat Transfer Label (HTL) department of label manufacturing factory. Project targeted waste heat from infrared dryer systems. Gemba Kaizen and A3 problem-solving methodologies were applied. By installing crossflow heat exchangers and deploying Lean-based monitoring and control measures, the project achieved a 28% reduction in electricity usage per dryer and saved over 2.4 million kWh annually. The study illustrates the potential of Lean to drive both operational excellence and environmental sustainability.

Keywords: Lean Manufacturing, Energy Efficiency, Heat Recovery, Sustainable Manufacturing, Gemba Kaizen, A3 Problem-Solving.

1 INTRODUCTION

Manufacturing industries play a significant role in global energy consumption, accounting for a considerable share of greenhouse gas emissions. This reality highlights the necessity for industries to adopt sustainable practices that reduce both energy usage and environmental impacts. Within industrial operations, drying processes, particularly those utilizing infrared (IR) technology, represent notable opportunities for energy efficiency improvement. Typically, these systems involve heating ambient air and subsequently releasing the heated exhaust air directly into the environment, leading to significant waste of thermal energy.

In the context of global climate concerns and the rise of sustainability reporting in supply chains, energy consumption in manufacturing has become a central issue. The industrial sector accounts for over 38% of global final energy consumption and contributes nearly a quarter of global CO₂ emissions [1]. Consequently, improving energy efficiency in manufacturing is seen as not only a business necessity but a climate imperative.

Recent literature emphasizes that traditional Lean Manufacturing frameworks, initially designed to minimize operational wastes such as overproduction, waiting, and excess processing, can also effectively address energy

inefficiencies [2]. Specifically, energy waste has increasingly been recognized as an implicit "eighth waste," deeply embedded within various operational inefficiencies yet often overlooked in conventional lean applications.

Heat recovery techniques, such as reusing exhaust heat to preheat incoming air streams, have emerged as effective strategies to enhance energy efficiency in industrial dryers. These approaches align closely with Lean-Green principles, leveraging systematic problem-solving methodologies such as Gemba Kaizen and the A3 approach to deliver both operational and sustainability improvements.

This study investigates the Heat Transfer Label (HTL) department at Avery Dennison Vietnam, a prominent supplier for global sportswear brands, including Adidas and Nike. In 2024, the HTL department alone was responsible for approximately 39% of the facility's total electricity usage, primarily due to its infrared drying systems. To address this substantial energy demand, this research applies Lean methodologies to implement a crossflow heat exchanger system that captures residual heat from exhaust air to preheat incoming fresh air. By reusing this otherwise wasted heat, the study aims to significantly reduce electricity consumption and associated CO₂ emissions, demonstrating the practical integration of Lean principles in achieving tangible sustainability outcomes.

2 LITERATURE REVIEW

Lean Manufacturing, originally developed to enhance operational efficiency by eliminating waste, has evolved to encompass environmental considerations, giving rise to the Lean-Green paradigm [3]. This approach integrates traditional Lean principles with environmental management strategies to reduce resource consumption and minimize ecological footprints.

A critical aspect of this integration is the recognition of energy waste as a form of non-value-adding activity. The U.S. Environmental Protection Agency (EPA) emphasizes that energy inefficiencies often stem from traditional wastes identified in Lean methodologies. By addressing these inefficiencies, organizations can achieve both economic and environmental benefits.

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For instance, a study conducted in the food processing industry demonstrated that integrating a gas-to-gas heat recovery system [4] in industrial baking ovens led to a 4% reduction in fuel consumption and a decrease of approximately 43 tons in CO₂ emissions annually. This was achieved by preheating the combustion air using the exhaust heat, thereby enhancing the overall energy efficiency of the process.

Furthermore, the U.S. Department of Energy highlights that process heating systems account for a significant portion of energy consumption [5] in manufacturing. Implementing waste heat recovery systems, such as recuperators and regenerators, can substantially reduce energy demand and associated emissions.

These findings underscore the potential of combining Lean methodologies with waste heat recovery technologies to achieve energy efficiency and sustainability goals in industrial settings.

3 CASE STUDY

This case study focuses on the Heat Transfer Label (HTL) department at Avery Dennison Vietnam, a manufacturing site specializing in high-performance labelling solutions for global sportswear brands. The factory, located in Long Hau Industrial Park, Vietnam, comprises several production lines, with the HTL line standing out due to its high energy consumption. In 2024, this department alone accounted for approximately 39% of the total electricity usage of the site. Rising energy costs, a tightening focus on sustainability from international customers, and corporate environmental commitments motivated the company to initiate a Lean improvement project. The objective was to enhance both operational efficiency and environmental performance by recovering waste heat from the infrared (IR) drying systems. The key metric studied in this project was electricity consumption in the dryers, directly linked to both operational costs and carbon emissions.

3.1 Problem statement

At the start of this project, the HTL department was facing challenges in energy efficiency. Infrared dryers, critical for the ink curing process, consumed large amounts of electricity by continuously heating fresh ambient air from 30°C to

120°C. After the drying process, hot air at approximately 110°C was expelled directly into the environment without recovery, resulting in significant thermal energy loss. This not only inflated energy costs but also led to higher carbon emissions, adversely impacting the factory's environmental footprint. Thus, there was a clear opportunity to design a Lean-based countermeasure that would recover heat without compromising the core drying process.

4 METHODOLOGY

Given our interest in exploring the ability of Lean tools and methods to improve both operational and sustainability metrics, a typically Lean approach was followed. It is coherent with the Gemba Kaizen multi-stage event approach described by Martin [6] and Osterling and Hamel [7]. The activities that took place during the Kaizen event execution followed the six-step structured problem-solving method provided by the A3 framework.

The case study was conducted in the Heat Transfer Label (HTL) department, focusing specifically on the drying systems where the highest energy consumption was observed. The entire project took approximately three and a half months to be completed. The specific steps involved in each of the three phases, depicted in Table 2, as well as their duration, are detailed below:

4.1 Kaizen Event Planning (duration: 2 weeks):

- Definition of the event scope (energy efficiency improvement in IR dryers)
- Selection of cross-functional team members (Production, Maintenance, Engineering, Procurement)
- Collection of relevant baseline data (energy consumption, inlet and exhaust air temperatures)
- Planning and scheduling of the Kaizen workshop.

4.2 Kaizen Event Execution (duration: 2 months):

- Establishment of ground rules, agenda, and Lean methodology to be followed
- Definition of the problem (step 1 of A3 Problem Solving): excessive electricity consumption due to unrecovered exhaust heat
- Characterization of the current condition and baseline performance (step 2 of A3 Problem Solving)
- Goal setting and desired future state definition (step 3 of A3 Problem Solving): at least 15% energy reduction
- Root cause analysis (step 4 of A3 Problem Solving) using the 5 Whys technique
- Development and pilot implementation of the countermeasure—crossflow heat exchangers (step 5 of A3 Problem Solving)
- Definition of a control plan (step 6 of A3 Problem Solving) including real-time monitoring and maintenance procedures.

4.3 Kaizen Event Follow-up—stabilization (duration: 1 month):

- Continuous monitoring of energy savings and system performance
- Standardization of new operating procedures, training for operators and maintenance staff, and assurance of long-term process stability.

4.4 Kaizen Event Planning

The first phase involved a careful planning stage to define the scope, assemble a cross-functional team, and establish clear performance metrics. Electricity consumption data from 2024 highlighted the HTL department as the highest energy consumer within the facility, with infrared dryers accounting for nearly 78% of its total electricity usage.

In collaboration with maintenance, engineering, production, procurement, and continuous improvement teams, the project team set a clear goal: to achieve at least a 15% reduction in electricity consumption for selected dryers by March 2025. Data collection included baseline measurements of inlet and exhaust air temperatures, energy consumption rates, and dryer operating profiles. Planning also involved the identification of technical constraints, particularly the critical need to maintain solvent and moisture evacuation to avoid compromising ink curing quality.

4.5 Kaizen Event Execution

Gemba walks were conducted to observe the drying process in its natural working environment. Through direct observation and operator interviews, the team confirmed that after the ink drying process, exhaust air at around 110°C was vented without any recovery system. The dryers required continuous heating of fresh ambient air from 30°C to 120°C, leading to significant electrical load.

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An A3 report was developed to systematically document the problem as shown in Table 1. The key observation was that although part of the exhaust air must be released to maintain humidity and solvent control, the residual heat carried by the exhaust air presented a substantial opportunity for recovery without compromising process integrity

Table 1: A3 Problem-Solving for heat loss in HTL drying process

Title/Problem		Decrease Energy Consumption at Printer Dryer – HTL Production Line
I. Background		
HTL uses 39% of total electricity (2024 data), making it the highest-consuming single production line, with a rising trend as on Figure 1. Within HTL, 78% of energy is consumed by 30 printer sets, 10% by AHU, and 2% by lighting (Figure 2) Therefore, Dryers are the primary focus of this study to reduce energy consumption through Lean improvement.		
II. Current condition		
After printing, wet-ink labels are transported directly from the printing press to the dryer via an inline conveyor system for immediate drying. The dryer includes 3 electric heating units equipped with infrared lamps, which heat fresh air from ambience temperature (~30°C) up to 120°C to cure the ink. A large portion of the hot exhaust air, after drying the ink, is released outside through an exhaust duct which temperature is around 110°C (Figure 3). Unfortunately, this unrecovered heat can be considered energy waste		
III. Goals/Targets		
Reducing or reusing the heat loss in exhausted air Achieve at least 15% reduction in electricity consumption in demo dryers' unit by end of Mar-2025		
IV. Analysis		
Root Cause (5 Whys Analysis) Problem: High energy consumption from the dryer → Why? → Requires continuous electric heating of fresh air to 120°C → Why? → Fresh air is supplied partially and heated from ambient temperature every cycle → Why? → Exhaust air is vented out partially with moisture/solvent after drying the ink → Why? → System is designed only for moisture/solvent removal, not for heat recovery		What-if Scenario: What if we block or reduce the exhaust air? ✓ Moisture and solvents would accumulate inside the dryer ✓ Results in high humidity, causing longer drying time or ink quality defects
Conclusion: While part of the exhaust air must be released to ensure product quality and safety, the heat it carries is currently wasted. This uncovers a clear opportunity for energy recovery through heat exchange before discharge.		
V. Countermeasures		

Install a heat exchanger to recover heat from the exhaust air and preheat incoming fresh air, reducing electricity demand on electric heaters.

Working Principle:

Total fresh air goes through the inner pipes of the heat exchanger, while the hot exhaust air from the dryer flows through the outer space of those pipes. The hot air & cold air will transfer the heat through the surface of the pipes (Figure 4).

Design Requirements:

- ✓ No impact on exhaust airflow for moisture/solvent removal
- ✓ Ensure high efficiency in heat recovery, low pressure drop, and resistance to humidity/solvent
- ✓ Enable regular cleaning; include temp & pressure sensors for monitoring.

Investment feasibility:

- ✓ Benefit/Cost: saving gains from energy consumption reduction vs investment value
- ✓ Investment payback year and Internal Rate of Return (IRR)
- ✓ Other benefits: sustainability (CO₂ reduction)

VI. Implementation

A new system is designed as on Figure 5. It is validated by engineering department and other relative departments before implementation.

The heat exchanger pilot project in the HTL department is summarised as in Table 2.

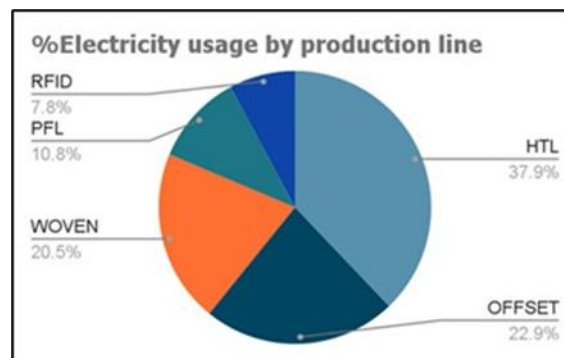


Figure 1: Electricity usage breakdown by production line across the factory

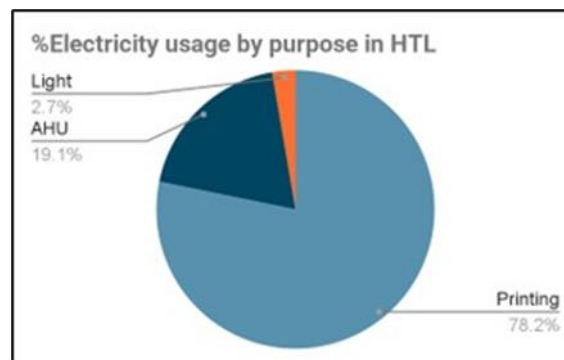


Figure 2: Electricity usage breakdown by purpose within the HTL department

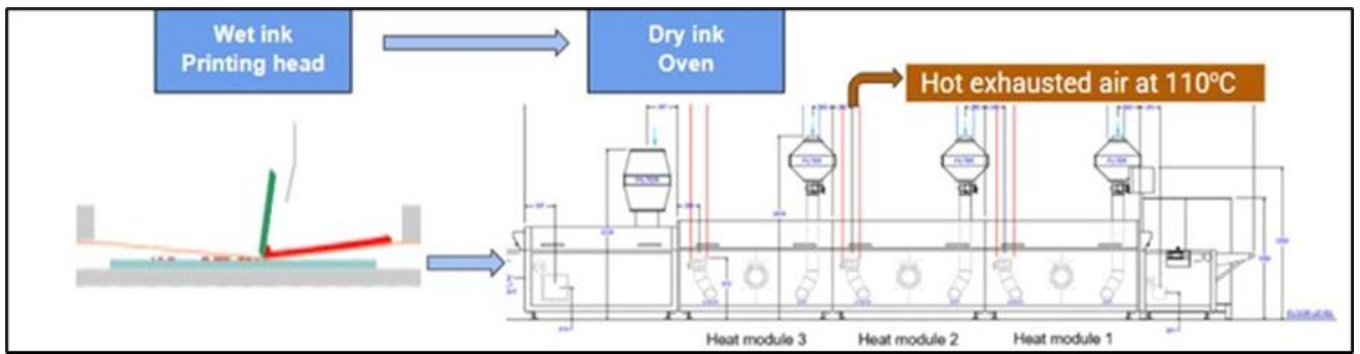


Figure 3: Diagram of the HTL infrared drying process showing wet-ink printing, drying oven modules, and exhaust air release at 110°C

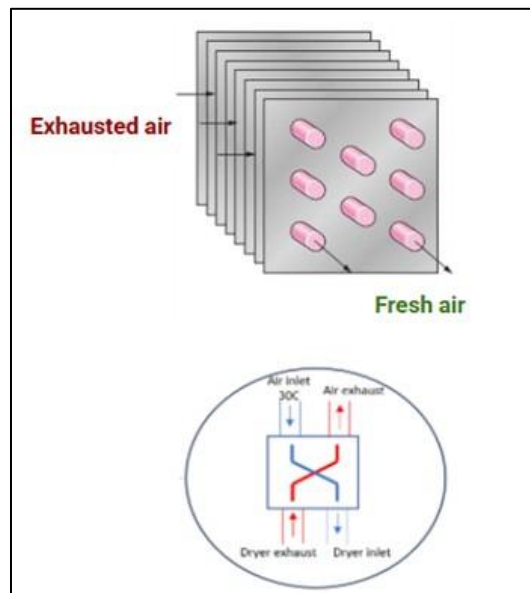


Figure 4: Illustration of the working principle of the crossflow heat exchanger

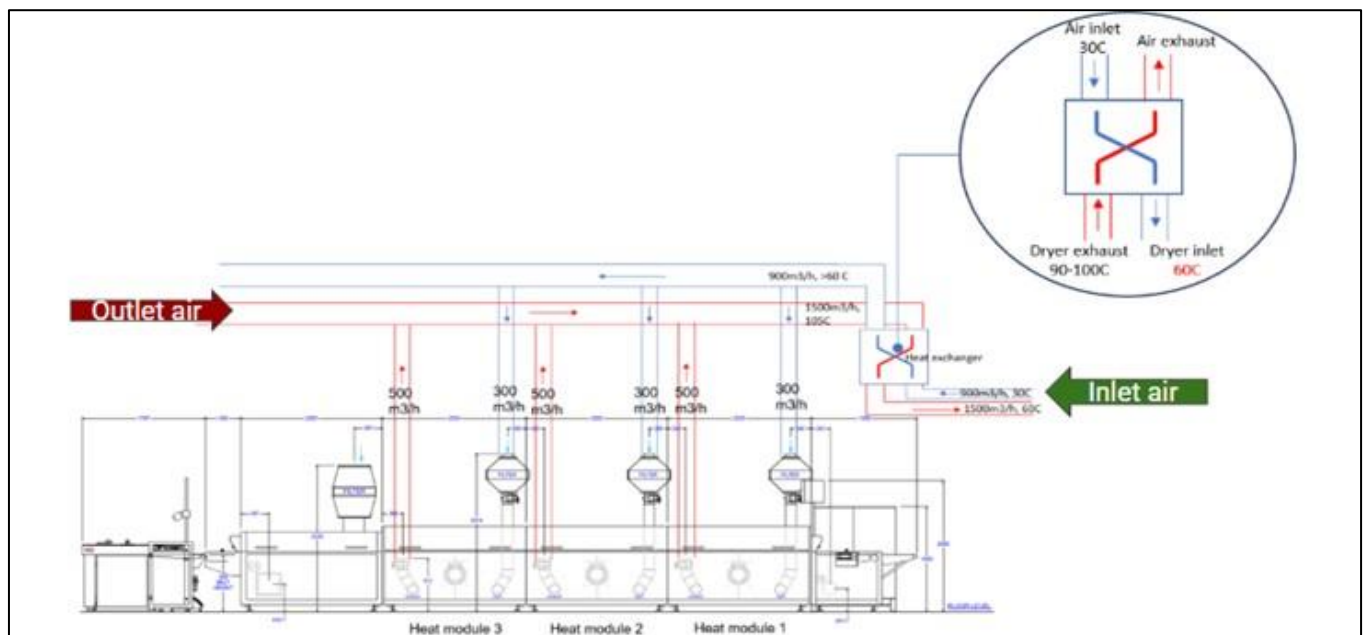


Figure 5: System layout of the HTL drying line with integrated crossflow heat exchanger, illustrating the airflow paths and heat recovery mechanism

Table 2: Implementation timeline and responsibilities for heat exchanger pilot project in the HTL department

Action	Key deliverables	Timeline	Responsible
Planning	Identify target and finalize technical requirements	Dec'24	Maintenance + Process Engineer (PE)
Sourcing & Bidding	Vendors present proposal and quotation	Week#3 (Jan'25)	Procurement
Investment Request	Request approval for a demo (2 sets)	Week#4	PE
Installation	Install heat exchanger system on selected dryers	Week#8 (Feb'25)	Vendor
Testing & Commissioning	Verify performance (temp, pressure, kWh) post-installation	Week#10	Production + Maintenance + PE

5 DEFINITION OF THE PROBLEM

The Gemba observations and baseline data collection revealed that the infrared drying systems in the HTL department operated with considerable energy inefficiency. Fresh ambient air at approximately 30°C was heated continuously to 120°C using electric infrared heaters. After curing the ink, the exhaust air—still at a high temperature of around 110°C—was directly vented outside without any form of heat recovery. This resulted in significant thermal energy loss, contributing to excessive electricity consumption and elevated production costs. Recognizing that moisture and solvent removal were essential for maintaining ink quality, the challenge was defined as reducing electricity consumption without compromising the drying process or product standards.

6 SETTING OF IMPROVEMENT GOALS

Following the problem definition, the team established clear and measurable improvement goals. The primary objective was to implement a solution that would recover waste heat from the exhaust air and preheat the incoming fresh air, thereby decreasing the energy load on the electric heaters. The specific target set for the pilot phase was to achieve at least a 15% reduction in electricity consumption for the selected demo dryers by the end of March 2025. This quantitative target provided a concrete benchmark to evaluate the effectiveness of the countermeasures and guided the decision-making process throughout the project.

7 ROOT-CAUSES ANALYSIS

A detailed root cause analysis was conducted using the 5 Whys methodology. It was determined that the continuous high energy demand stemmed from the system's design, which required fresh ambient air to be heated from 30°C to 120°C for each drying cycle. Although venting the exhaust air was necessary to remove moisture and solvent residues, the original dryer design did not incorporate any mechanism to recover the thermal energy contained in the exhaust stream.

To deepen the analysis, a What-If Scenario was explored. The team considered the possibility of reducing or blocking part of the exhaust flow in order to retain more heat within the system. However, this approach posed significant risks: accumulation of moisture and solvents inside the dryer could lead to higher humidity levels, prolong drying times, and critically impair ink curing quality. Thus, reducing exhaust flow was deemed impractical as it would compromise both product quality and operational stability.

The analysis concluded that while maintaining a certain exhaust volume was essential for safe and effective drying, the heat carried away by this exhaust air represented a missed opportunity for energy recovery. Consequently, the root cause was identified as the absence of a dedicated heat recovery system capable of reclaiming waste heat without disrupting the essential solvent removal function.

8 DEFINITION OF PLANNED COUNTERMEASURES (ACTION PLAN)

Based on the insights gained from the root cause analysis, the project team developed a targeted countermeasure: the installation of a crossflow heat exchanger system. The proposed design allowed fresh incoming air to pass through internal pipes, while hot exhaust air flowed across the external surfaces, facilitating efficient heat transfer without mixing air streams. This configuration ensured that the solvent removal function was preserved while simultaneously preheating the fresh air, thereby reducing the electricity demand on the heating elements.

Technical requirements for the heat exchanger included high thermal efficiency, low pressure drop, resistance to solvent-laden moisture, and ease of maintenance. Temperature and pressure sensors were integrated into the system to enable real-time performance monitoring. Following a competitive bidding process, a vendor was selected, and a

phased implementation plan was established, starting with a pilot on four dryers to validate performance before broader rollout.

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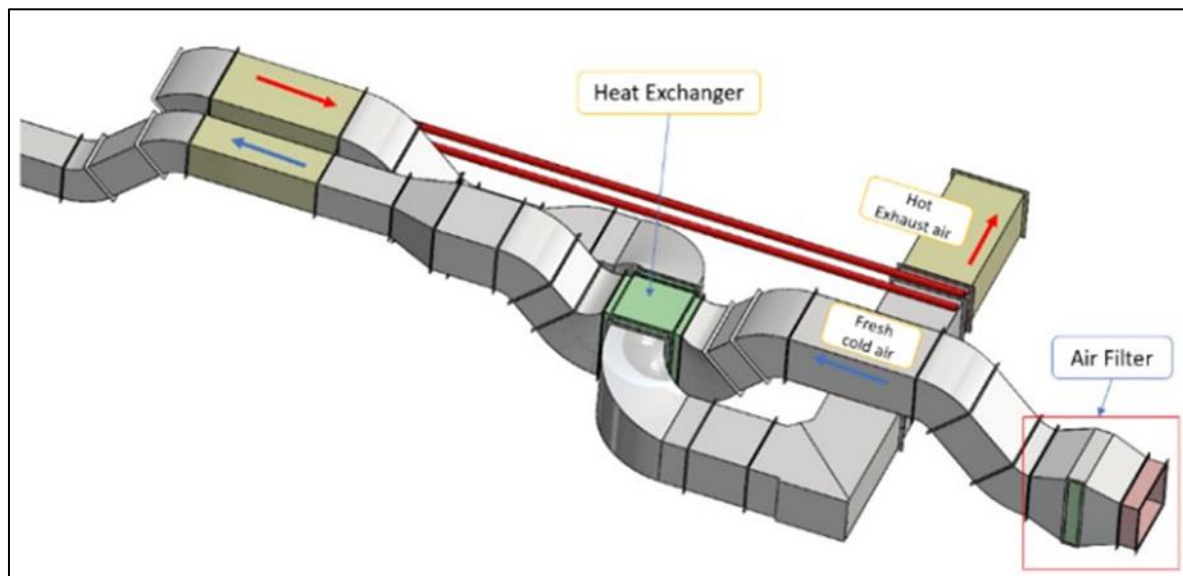


Figure 6: Schematic diagram of the crossflow heat exchanger system applied in the HTL dryer process, showing the airflow paths of fresh intake air and hot exhaust air

The implementation of the crossflow heat exchanger system in the HTL department resulted in significant improvements in both operational performance and environmental sustainability metrics. During the initial pilot phase (Phase 1), heat exchangers were installed on four infrared dryers. Energy monitoring conducted over several weeks demonstrated a consistent reduction in electricity consumption, with no adverse impact on product quality or drying time.

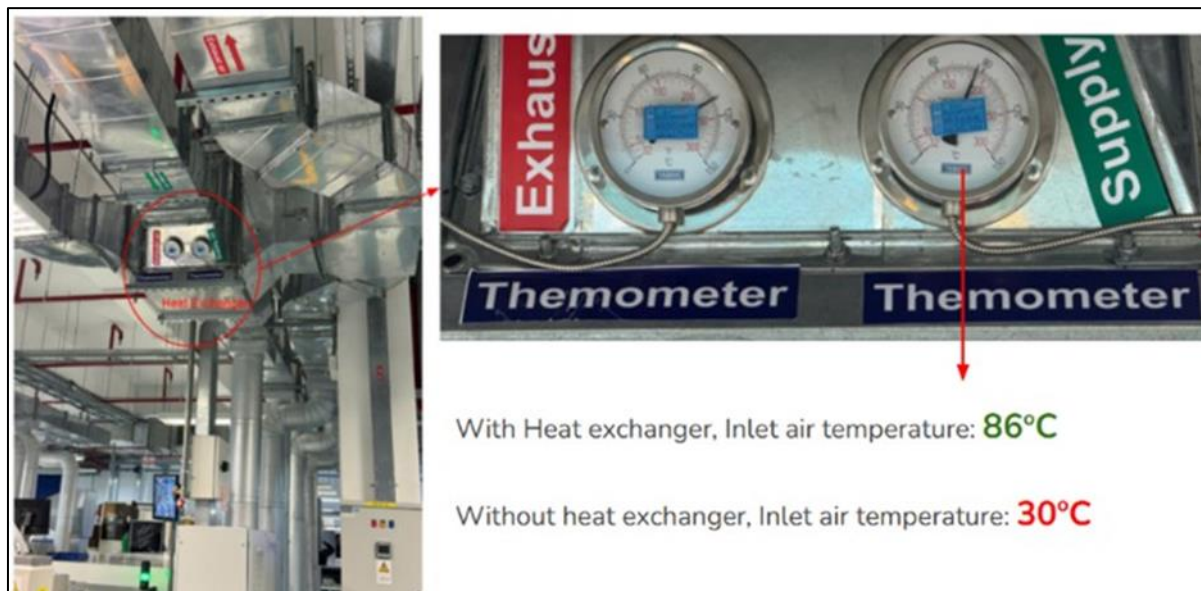


Figure 7: On-site temperature monitoring system showing inlet air temperature after heat exchanger installation

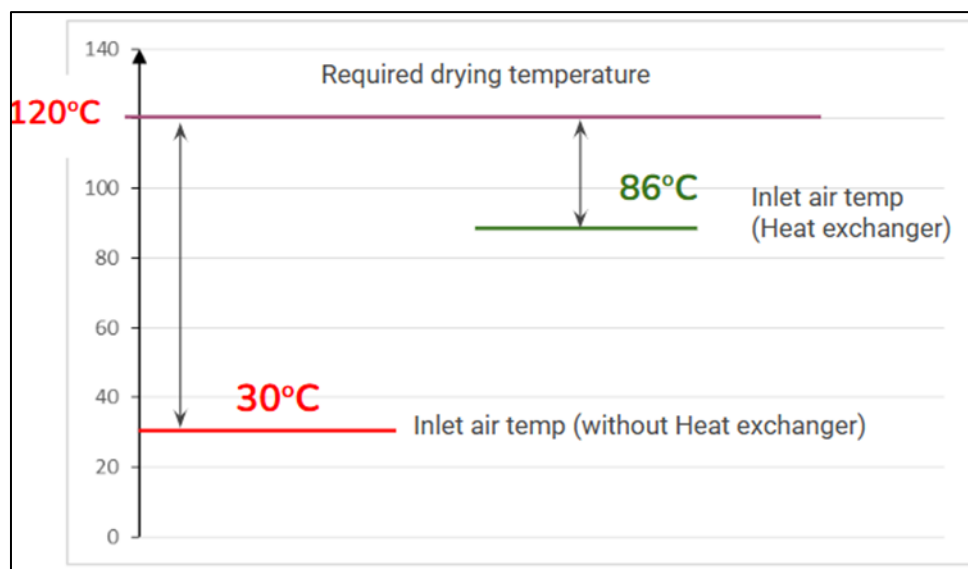


Figure 8: Comparison of inlet air temperature before and after heat exchanger implementation, demonstrating the reduced heating requirement to reach the drying setpoint of 120°C

A key mechanism behind this improvement was the preheating of the fresh air entering the dryers. As illustrated in Figure 8, the inlet air temperature without the heat exchanger was approximately 30°C. After installing the heat exchangers, the inlet air temperature increased to around 86°C before entering the heating chamber. Consequently, the electrical heaters only needed to supply the additional energy to raise the temperature from 86°C to the required drying temperature of 120°C, rather than from 30°C to 120°C as previously. This significant reduction in required heating load directly translated into substantial energy savings.

Quantitatively, the pilot achieved an energy consumption reduction of 28.7%, decreasing from an average of 71.4 kWh per dryer per hour to 50.9 kWh. The annualized electricity savings for the four pilot units were estimated at 370,312 kWh, corresponding to a cost saving of USD 26,436 per year. In environmental terms, the pilot implementation resulted in an estimated reduction of 250 tons of CO₂ emissions annually. Financial analysis indicated a payback period of approximately 2.6 years, making the investment highly attractive from both operational and sustainability standpoints.

Building upon the successful pilot results, plans were formulated to expand the heat exchanger installation across all 30 dryers within the HTL department. Full-scale implementation is projected to yield annual energy savings of 2,407,033 kWh and an annual cost reduction of approximately USD 171,835. The corresponding environmental benefit would amount to a reduction of 1,625 tons of CO₂ emissions per year. Importantly, even with the expanded scope, the project maintains a favourable payback period of around 2.6 years, reinforcing the strong business case for full deployment.

9 DISCUSSION AND SUGGESTION

The pilot implementation of the crossflow heat exchanger system in the HTL department demonstrated outstanding success in achieving targeted improvements in both operational efficiency and sustainability performance. By increasing the inlet air temperature from 30°C to approximately 86°C, each infrared dryer reduced its electricity consumption by 28% without compromising drying quality or solvent evacuation efficiency. Real-time monitoring confirmed the stability of these improvements across production shifts. In financial terms, the energy savings per unit translated into an attractive payback period of 2.6 years, highlighting the strong economic justification for the investment.

Building on the encouraging pilot results, it is strongly recommended to extend the heat exchanger system to all 30 dryers across the HTL production line. Full-scale deployment is projected to deliver total annual electricity savings exceeding 2.4 million kWh, equivalent to a reduction of approximately 1,625 tons of CO₂ emissions. Notably, even when considering the larger scope of investment, the overall payback period for the expanded project remains favourable at approximately 2.6 years, reinforcing the strong return on investment from both operational and sustainability perspectives. Beyond the immediate energy and cost savings, full implementation would enhance the company's alignment with global sustainability standards increasingly demanded by major brand customers.

Furthermore, the successful model developed through this project suggests significant potential for broader replication within other departments and manufacturing sites of Avery Dennison. Processes involving high-temperature curing, drying, or heating that currently vent untreated exhaust air could similarly benefit from waste heat recovery solutions. Conducting systematic energy audits across other facilities could reveal additional opportunities to apply Lean-based heat recovery, thereby amplifying the positive environmental and financial impact company-wide. In reflecting on the factors that contributed to the project's success, two critical elements emerge. Firstly, the emphasis on "going to Gemba"—direct shopfloor observation—allowed the project team to uncover hidden inefficiencies that would not have been evident through data analysis alone. Understanding the real process conditions was instrumental in designing a solution that addressed the true root causes rather than surface symptoms. Secondly, the cross-functional collaboration among production, maintenance, engineering, and procurement teams played a vital role. This integrated approach ensured that technical feasibility, operational practicality, and financial viability were fully considered from the outset, enabling fast and effective project execution.

10 CONCLUSION

Overall, this case study reinforces the powerful synergy between Lean methodologies and energy management initiatives. By treating unrecovered thermal energy as a hidden form of waste, and systematically addressing it through structured Lean problem-solving, the project achieved tangible operational, financial, and environmental benefits. It provides a clear demonstration that Lean thinking, traditionally associated with productivity improvements, can be successfully leveraged to drive sustainable manufacturing transformation.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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