CORRUGATED BOARD PRODUCTION AND CONVERSION

BEST PRACTICE HANDBOOK FOR IMPROVED ENERGY EFFICIENCY

@2024 - 1st EDITION

BEST PRACTICES HANDBOOK CORRUGATED BOARD

BEST PRACTICES HANDBOOK FOR IMPROVED ENERGY EFFICIENCY

REPORT PREPARED BY RISE BIOECONOMY AND HEALTH ON THE BEHALF OF FEFCO

Sennai MESFUN
RISE RESEARCH
INSTITUTES OF SWEDEN

Astrid GLASENAPP
RISE RESEARCH
INSTITUTES OF SWEDEN

Michael STURGES
RISE RESEARCH
INSTITUTES OF SWEDEN

Tatjana KARPENJA
RISE RESEARCH
INSTITUTES OF SWEDEN

Michael FREY
CONSULTANT
FOR FEFCO

REPORT PREPARED BY RISE BIOECONOMY AND HEALTH ON THE BEHALF OF FEFCO

EXECUTIVE SUMMARY

This book offers a comprehensive guide to enhancing energy performance in corrugated board production and conversion processes, aligning with the industry's Climate Neutrality Roadmap (CNR) 2050. The CNR outlines three key strategies for reducing CO2 emissions within the corrugated industry: material efficiency, energy efficiency, and decarbonization.

To provide a thorough understanding of best practices, this handbook adopts a multifaceted approach. It includes a questionnaire to gather valuable insights and practices for knowledge sharing among industry peers, fostering cross-pollination of ideas. Additionally, interviews with industry experts, equipment manufacturers, and suppliers enrich the content with their perspectives and expertise.

Furthermore, a collaborative workshop involving industry experts and decision-makers was organized to prioritize identified best practices and encourage discussions. This approach ensures that the book comprehensively addresses challenges, opportunities, and potential solutions within the corrugated board industry.

The book emphasizes the need for sustainability and presents a collection of proven strategies and techniques to enhance energy efficiency in the industry. These best practices encompass various aspects of production, conversion, and energy management, with a focus on short-term, typically 1 to 3-year, implementable solutions. Readers will gain valuable insights into optimizing energy usage.

By adopting the recommended practices outlined in the book, corrugated board manufacturers and converters can achieve significant energy savings, reduce carbon emissions, and enhance operational efficiency. It serves as an invaluable resource for industry professionals, managers, engineers, and sustainability practitioners seeking practical insights and actionable steps to improve energy performance in corrugated board production and conversion processes. The inclusion of expert perspectives and insights from decision-makers ensures alignment with the industry's priorities and aspirations.

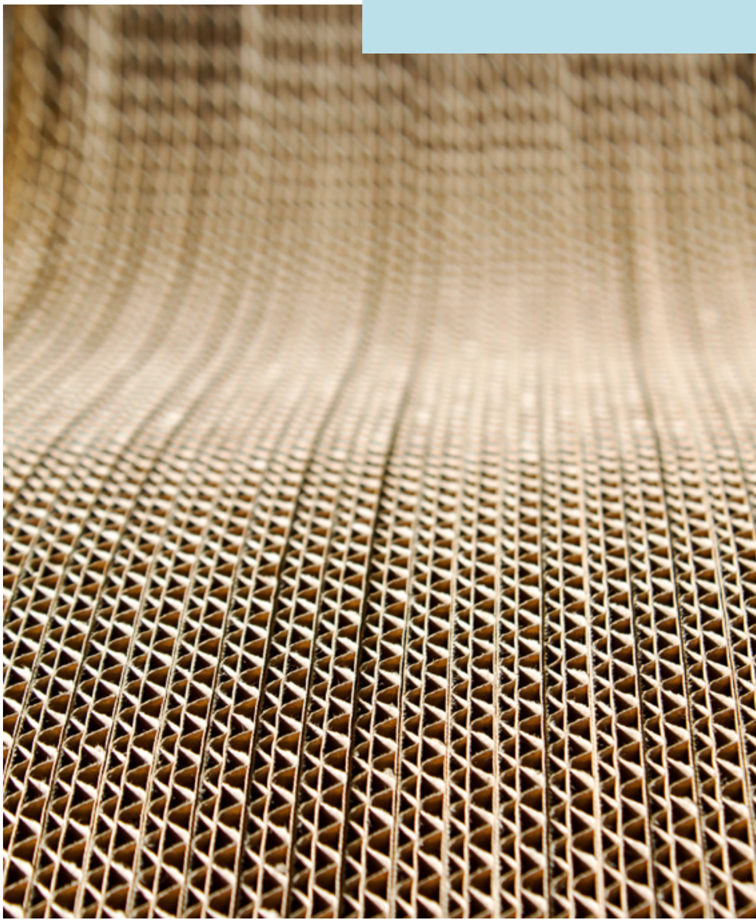


TABLE OF CONTENTS

PREFACE

Welcome to the best practices handbook on improved energy performance in corrugated board production and conversion. This handbook aims to provide valuable insights, practical strategies, and best practices that can be implemented within the corrugated board industry to enhance energy efficiency and drive sustainability in line with the industry's Climate Neutrality Roadmap 2050.

The corrugated board industry plays a pivotal role in ensuring efficient supply chains and protecting goods during their transit from producers to customers. However, the energy consumption associated with these manufacturing processes poses challenges in terms of environmental impact, cost management, and long-term sustainability.

To address these challenges and provide practical solutions, a collaborative approach was taken in developing this handbook. A questionnaire was utilized to collect practices and experiences from industry compatriots, enabling the exchange of knowledge and real-world insights. Additionally, interviews were conducted with industry experts and equipment manufacturers and suppliers to incorporate their perspectives and expertise into the content.

> **From a FEFCO perspective, 2022 has been a year of frenetic efforts to mitigate the potential consequences of harmful legislation. While simultaneously developing the Climate Neutrality Roadmap to demonstrate the corrugated industry's commitment to sustainability and carbon neutrality by 2050 or earlier. Corrugated cardboard is one of the best sustainable packaging solutions.**
>
> *Eleni Despotou*
> *FEFCO Director General*

Furthermore, a workshop was organized, bringing together industry experts and decision makers to discuss and prioritize the identified best practices. This collaborative effort ensures that the book encompasses a comprehensive understanding of the industry's current state, challenges, and future aspirations.

The chapters in this handbook cover a wide range of topics related to steam generation and distribution, corrugating, converting, compressed-air systems and auxiliaries as well as those related to monitoring and organisation.

We hope that this handbook will serve as a valuable resource for industry professionals, managers, engineers, and sustainability practitioners seeking practical guidance on improving energy performance in corrugated board production and conversion processes. By adopting the recommended strategies and best practices, we believe that the industry can achieve substantial energy savings, reduce environmental impact, and enhance overall operational efficiency.

We extend our gratitude to all the contributors, industry experts, and participants who have generously shared their knowledge and experiences. Their collective wisdom and commitment to sustainability have been instrumental in shaping the content of this handbook.

The authors, FEFCO and Sustainable Manufacturing Workgroup.

INTRODUCTION

The European corrugated board industry is an important industrial sector in Europe. With a production of around 50 billion square meters of corrugated board in 2021, it plays a crucial role in packaging and supply chain operations. The industry encompasses 660 plants spread across Europe. These plants are engaged in the manufacturing of corrugated board and corrugated packaging. Approximately 400 companies are involved in the European corrugated board industry. These companies directly employ around 100,000 people, contributing to job creation and economic growth. Corrugated board packaging offers several advantages in terms of supply chain efficiency. It is designed to protect goods during transportation and safeguards products, ensuring their safe delivery from producers to customers.

The plants producing corrugated board and converting the board into packaging can be classified into three types:

- **Sheet feeders/sheet plants:** These plants receive liner and fluting paper and manufacture corrugated board in sheet form. The produced corrugated board sheets are then sold to converting plants or box plants for further processing into corrugated products such as boxes and point-of-sale display stands.
- **Converting plants/box plants:** Converting plants receive the corrugated board sheets from sheet feeders/sheet plants and convert them into various corrugated products. This can include the production of corrugated boxes, point-of-sale display stands, and other similar items.
- **Integrated plants:** Integrated plants have a comprehensive production process within their facilities. They take in liner and fluting paper and produce cor rugated board in-house. The produced corrugated board is then converted into corrugated products, including boxes and point-of-sale display stands, directly within the integrated plant. Approximately 95% of the corrugated board produced in integrated plants is converted into boxes on-site. However, integrated plants may also purchase some corrugated board in sheets from other sheet plants to supplement their own production. Additionally, they may sell some corrugated board in sheets to other box plants. It's worth noting that the majority of corrugated board production in Europe takes place in integrated plants.

ENERGY CONSUMPTION IN CORRUGATED BOARD PRODUCTION AND CONVERSION

Like all manufacturing processes, the production of corrugated board and conversion into packaging requires energy inputs. The key energy requirements include:

- **Thermal Energy:** Heat and steam are essential for conditioning the paper, making it flexible for forming the fluted pattern and creating a bond between the papers during corrugated board production. Steam may also be used for adhesive production on-site. Moreover, depending on the location, space heating may be required during winter months to maintain suitable working conditions.
- **Electricity:** Electricity is required to power machinery throughout the processes of corrugation and conversion. It is also used for lighting, powering office equipment, and other auxiliary purposes. However, electricity consumption for non-production purposes is considered negligible compared to the energy consumed in the production processes.
- **Internal Transport:** Energy is required for the internal movement of raw materials and products using forklift trucks. The forklifts may be powered by electricity, LPG, or diesel oil. However, energy consumption for internal transport is typically minimal compared to the energy consumed in production processes.

Heat and steam are usually generated on-site using boilers, while electricity is generally purchased from electricity supply companies. In some cases, plants located alongside paper mills may receive heat, steam, and/or electricity directly from the paper mill.

Overall, according to Climate Neutrality Roadmap (FEFCO, 2023) it is estimated that in 2020 the European corrugated board sector consumed approximately 10.4 PJ of purchased electricity and 19.7 PJ of thermal energy to produce heat and steam.

Energy profile classified by source and plant type

This section describes typical specific energy consumption and its composition in the context of European corrugated board production and conversion. The data derives from another FEFCO survey focused on life cycle analysis (LCA). Fig. 1 illustrates the energy composition by source per plant type.

ENERGY USE BY SOURCE AND PLANT TYPE (%)

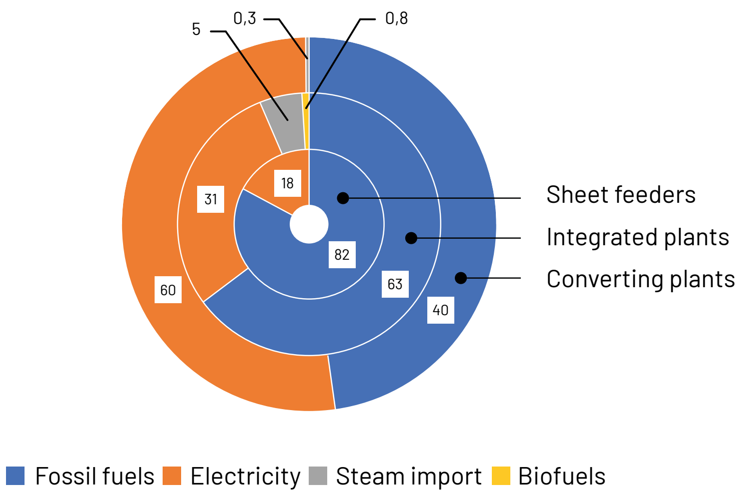


Fig. 1 Typical energy composition classified by source and plant type

Sheet plants/sheet feeders, which accounted for approximately 6% of the production of plants participating in the LCA survey, varied in production capacity between 30-130 kilotonnes per annum. The consumption of externally supplied total energy per tonne of net saleable product fall in the range 0.6–2 GJ/ t nsp, with an average of 1 GJ/t nsp. Analysis shows that there is only a limited relationship between total production at a sheet plants / sheet feeders and the total external energy inputs per tonne net saleable product.

Currently, fossil fuels used to produce thermal energy onsite account for 82% of total external energy inputs, with purchased electricity accounting for the remaining 18%, Fig. 1. Nearly, 100% of the sheet plants/sheet feeders participating in the LCA survey rely on natural gas as their only purchased thermal energy input.

Converting/box plants, which accounted for approximately 3% of the production of plants participating in the LCA survey, varied in production capacity between 1.3–27 kilotonnes per annum. The total energy consumption of converting plants fall in the range 0.1–2.5 GJ/t nsp, with an average of 0.7 GJ/t nsp. The wide range in total energy consumption reflects the wide variety of converting operations which can be employed at converting sites. Analysis shows that there is only a limited relationship between total production at a converting or box plants and the total external energy inputs per tonne net saleable product.

Currently, fossil fuels account for about 40% of total external energy inputs. Purchased electricity accounts for most of the remaining 60% with purchased steam accounting for less than 1%, Fig. 1. Nearly, 74% of the converting plants / box plants participating in the survey rely on natural gas as their main source of purchased thermal energy input. Light fuel oil and LPG accounts for the remaining purchased fossil fuels.

Integrated plants, which accounted for approximately 91% of the production of plants participating in the LCA survey, varied in production capacity between 10-140 kilotonnes per annum. For integrated plans the total energy consumption fall in the range 0.85–3.5 GJ/t nsp, with an average of 1.4 GJ/t nsp. Analysis shows that there is a limited relationship between total production at an integrated plant and the total external energy inputs per tonne net saleable product.

Currently, fossil fuels account for 63% of total external energy inputs, with biofuels accounting for less than 1%. Purchased electricity accounts for 31% and purchased steam accounts for the remaining 5% of total external energy inputs, Fig. 1. Almost 90% of integrated plants currently rely on natural gas as their main purchased thermal energy input. The remaining plants utilise primarily light fuel oil, with a few sites also using heavy fuel oil, diesel, LPG and coal. In terms of biofuels consumed, these include bark, wood biomass and black liquor supplied by a co-located papermill.

Understanding the variability of energy consumption

The wide ranges in energy consumption within each type of plant in the corrugated board industry can be attributed to various factors. Here are some factors that can contribute to the variation in energy consumption:

- **Product Type:** The energy requirements can vary depending on the specific products being produced. Different products may involve varying levels of complexity in the manufacturing process, requiring different energy inputs.
- **Process Waste:** The amount of process waste generated during production can impact the net saleable product. Higher waste generation may require additional energy for waste management and disposal.
- **Onsite Processes:** The specific processes performed onsite, such as the production of glue or printing operations, can influence the energy consumption. The presence and the kind of printing processes can add to the energy requirements.
- **Location and Size:** The geographical location and size of the plants can also contribute to energy consumption variations. Plants located in colder regions may in theory require additional energy for space heating during winter months, affecting their overall energy consumption. Certainly, below a latitude of approximately 45°N converting plants do in the energy survey do not require any thermal energy. Above this latitude, many plants require thermal energy although there is no clear relationship between latitude and thermal energy demand.
- **Plant layout and age:** A well-designed layout allows optimized equipment placement and the usage of a belt instead of a vacuum system for waste transportation. Older equipment may not incorporate the latest technological advancements aimed at energy savings and consume more energy compared to newer models.

Considering these factors, it is important to note that the lowest energy consumption values in the range provided may not be applicable to all producers. The energy consumption will vary based on the specific circumstances and characteristics of each individual plant, including their product mix, waste management practices, production processes, and location.

To accurately assess energy consumption and identify opportunities for energy efficiency improvements, a detailed analysis of each plant's operations and specific requirements would be necessary.

ENERGY PRODUCTION, CONSUMPTION AND GREENHOUSE GAS EMISSIONS

The commitment of the European corrugated cardboard sector, represented by FEFCO and its members, to achieve climate neutrality by 2050 (FEFCO, 2023) demonstrates their recognition of the importance of addressing greenhouse gas emissions. The roadmap for achieving this ambition emphasizes the significance of improving material and energy efficiency as well as the transitioning to a decarbonized energy mix as key strategies.

By focusing on material efficiency, energy efficiency, and decarbonisation, the sector aims to reduce its environmental footprint. According to the roadmap, these actions have the potential to achieve a reduction of 6.1 million tonnes of CO_2 equivalents (equivalent to 32%) in 2050 compared to a business-as-usual scenario.

Aside from the environmental benefits, energy efficiency is also important for economic reasons. Energy consumption represents a significant cost for producers and converters in the corrugated board industry. Therefore, optimizing energy use and reducing energy waste can lead to cost savings and enhance the competitiveness of businesses in the sector.

To support these objectives, FEFCO has commissioned the preparation of a document that highlights best practices and potential opportunities for energy efficiency in the European corrugated sector. This document aims to provide guidance and valuable insights for industry stakeholders to implement effective energy-saving measures and contribute to the sector's climate goals.

By focusing on energy efficiency, material efficiency and decarbonisation, the European corrugated board industry is taking proactive steps to address climate change, reduce greenhouse gas emissions, and ensure a sustainable future for the sector.

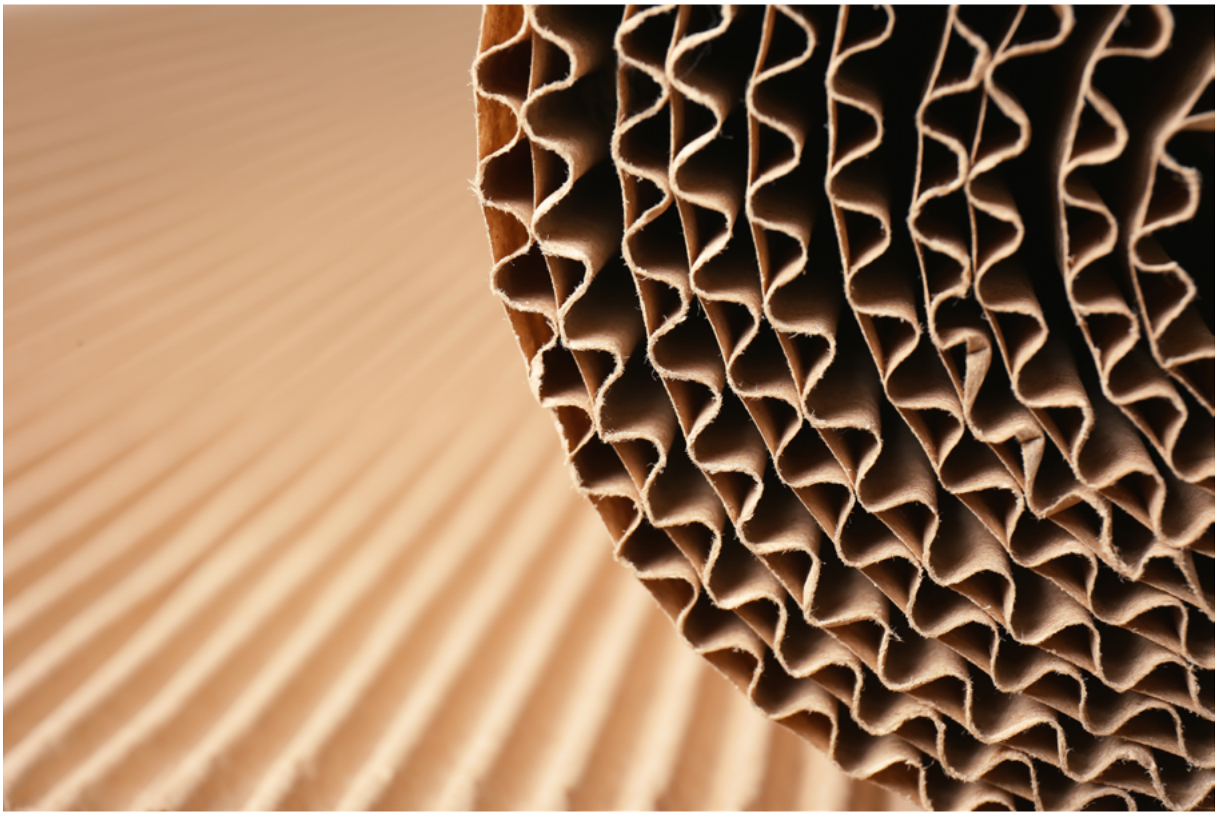
OBJECTIVES

The primary objective of this best practices handbook commissioned by FEFCO for the European corrugated board industry is to assist in identifying feasible energy performance improvement measures that can be implemented in the short term, specifically within a timeframe of 1 to 3 years. By focusing on the immediate and near-term perspective, the document aims to provide practical recommendations and actionable strategies that can be readily implemented by industry players.

The document is designed to support corrugated board production and converting companies in their efforts to enhance energy efficiency and reduce energy consumption. It will outline specific measures and best practices that can be adopted to achieve energy performance improvements within a relatively short timeframe.

By identifying and implementing these energy-saving measures, companies in the corrugated board industry can realize immediate benefits in terms of energy cost reduction, environmental sustainability, and improved competitiveness. The document will serve as a valuable resource to guide industry stakeholders in making informed decisions and taking effective actions to optimize their energy performance.

Ultimately, the objective is to facilitate the transition towards a more energy-efficient and sustainable corrugated board production and converting sector, aligning with the industry's commitment to climate neutrality by 2050.



METHODOLOGY

This best practice handbook is prepared based on information collected from corrugated board manufacturers and technology suppliers communicated in three forms, using a questionnaire, direct interviews and a workshop with experts.

Relevant quantitative data from the industry has been collected using an energy efficiency questionnaire prepared to suit all types of plant configurations, i.e., integrated plants, sheet feeders and converting plants.

RISE conducted a workshop with industry experts to discuss the results of the questionnaire and additional topics raised during interviews. The workshop helped to leverage their knowledge and expertise to drive meaningful discussions and generate actionable insights. The workshop served as a platform for collaboration, idea exchange, and consensus-building, leading to practicable solutions and a collective commitment towards improving energy efficiency in corrugated board manufacturing.

ENERGY EFFICIENCY QUESTIONNAIRE

The Energy Efficiency Questionnaire (EEQ) has been developed by RISE AB, in collaboration with an experienced consultant for FEFCO, and with the guidance of industry experts. The questionnaire incorporates input from external sources during its development, including the following references: (Chow et al., 2005; Daniela et al., 2012; DETR, 1996; Parr, 2021).

The EEQ is designed to thoroughly gather quantitative data that can be used to assess the status of energy efficiency measures within the corrugated industry.

Tool: The EEQ is prepared as an electronic questionnaire distributed to respondents in the form of an MS Excel spreadsheet, Fig. 2. This format allows for easy data input and enables efficient data analysis and consolidation. Respondents are requested to fill in the required information directly into the electronic EEQ and return it as an MS Excel spreadsheet. This ensures consistency and facilitates the collection of standardized data.

Topics: The EEQ categorizes the various process areas involved in corrugated board production and conversion into five distinct groups of topics, each focusing on energy efficiency. These topic groups are designed to cover specific aspects relevant to energy efficiency within each process area. The specific topics within each process area may vary, but they are tailored to capture key factors impacting energy efficiency in the corrugated industry. By covering a wide range of topics, the EEQ provides a holistic view of energy efficiency practices within the corrugated industry and enables a qualitative evaluation of the collected data.

The EEQ contains a total of 93 topics classified into five process areas:

- Steam generation (19)
- Corrugating (16)
- Converting (10)
- Auxiliaries (36, compressed-air system 15, lighting and factory heating 10, belt and drive systems 11)
- Monitoring and organisation (12)

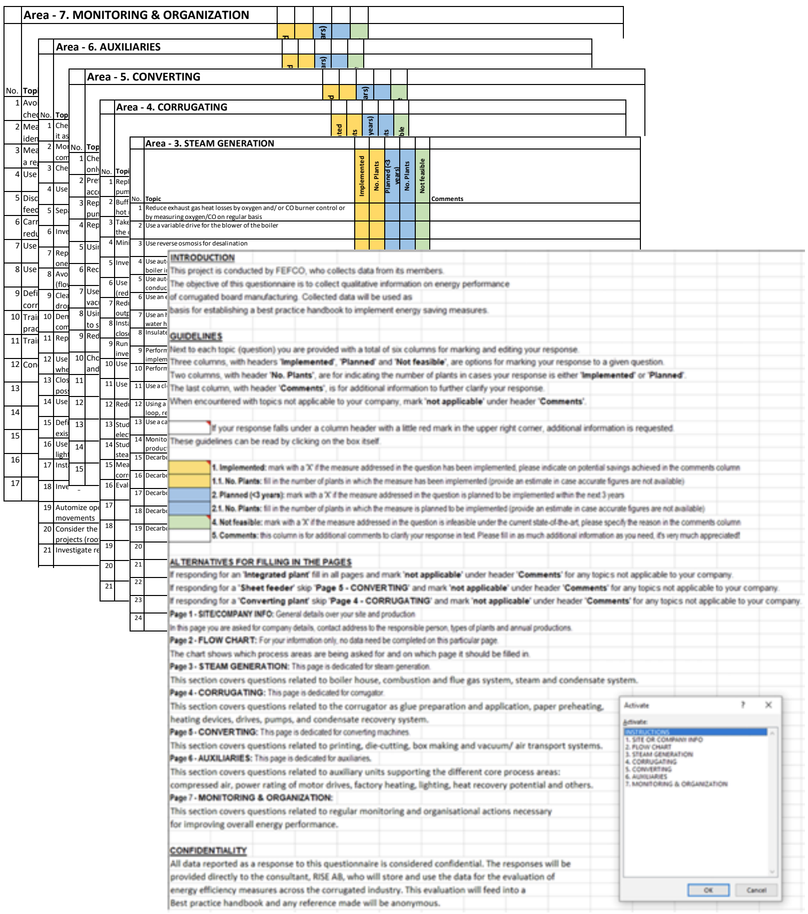


Fig. 2 Outline of the EEQ and the spreadsheet data structure

Data Collection: FEFCO, as the organization overseeing the EEQ, was responsible for distributing the questionnaire to the relevant stakeholders within the corrugated industry. FEFCO collected the responses from these stakeholders, which likely include corrugated board manufacturers, packaging companies, and other entities involved in the production and distribution of corrugated products. The aim was to obtain comprehensive data on energy efficiency measures from a wide range of industry participants. RISE, in collaboration with FEFCO, ensured that the respondents understood the response options provided in the questionnaire and encouraged them to provide accurate information regarding the status of each topic.

The responses covered a total of 115 plants across Europe of which integrated 99, sheet feeders 5 and converting 11. This corresponds to about 17% of the total number of corrugated board and conversion plants in Europe. The corresponding production amounted to 8.73 billion square meters, about 16% of total production in Europe.

Data Analysis: RISE analyzed the collected responses with focused on determining the implementation status of each topic within the EEQ, Fig. 3. The analysis identified the percentage of topics that were reported as implemented or planned in the short-term (<3 years) or considered infeasible. A new category with a label "not indicated for topic" was added to account for the difference between the maximum number of plants responded for a process area but not for the specific topic. This analysis provided valuable insights into the current state of energy efficiency practices within the corrugated industry.

While the responses cover a small fraction of the plants in Europe, analysing the data from the 115 plants can still provide valuable insights on energy performance and potential improvements. By leveraging the findings and extrapolating the results to the broader population, it is possible to make informed recommendations and encourage energy-saving initiatives in the corrugated board production and conversion.

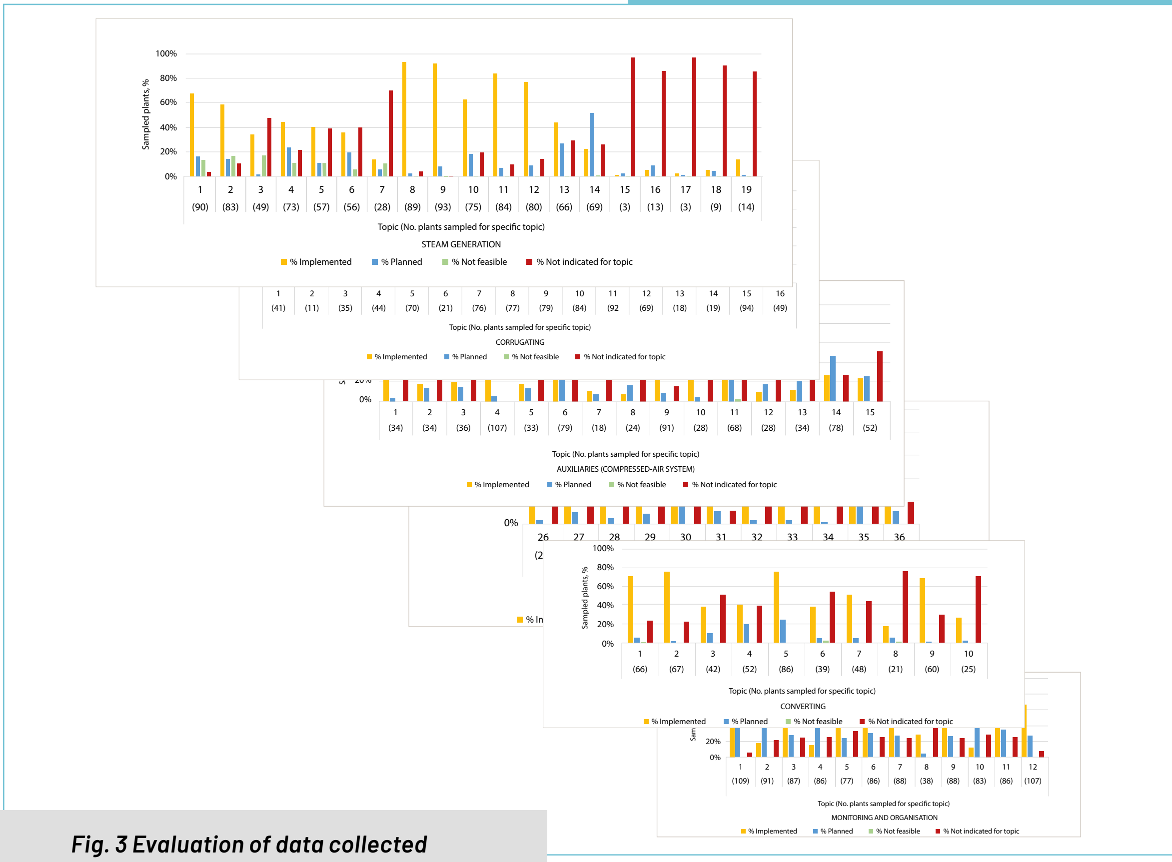


Fig. 3 Evaluation of data collected through the EEQ

INTERVIEW WITH EXPERTS AND TECHNOLOGY SUPPLIERS

To gather expertise and recommendations from equipment suppliers and industry experts in the European context, interviews were conducted as an extension of the energy efficiency questionnaire (EEQ). Interviews were conducted with technology suppliers in the following areas: steam and condensate system (2 suppliers), corrugator (2 suppliers), compressed-air systems (1 supplier), starch and glue system (1 supplier).

The interviews aimed to gather insights on core machinery used in corrugated board production and conversion processes. The input and perspectives obtained from these interviews were valuable in enhancing the content of the EEQ.

The interviews with equipment suppliers allowed for a deeper understanding of the latest technological advancements, energy-efficient features, and best practices related to the machinery used in the industry. The suppliers' expertise provided insights into the specific functionalities, performance optimization, and energy-saving opportunities associated with their equipment. Similarly, the interviews with industry experts focused on core machineries involved in corrugated board production and conversion. These experts, having hands-on experience and knowledge in the field, provided valuable insights into the operational aspects, energy optimization techniques, and potential areas for improvement within the production and conversion processes.

The information gathered through these interviews enabled the inclusion of additional topics in the EEQ, derived directly from the expertise and recommendations of equipment suppliers and industry experts. These added topics further enhanced the scope of the questionnaire, ensuring comprehensive coverage of energy efficiency considerations specific to the corrugated board industry.

By incorporating the perspectives of suppliers and industry experts, this handbook becomes a valuable tool for industry compatriots to exchange practices and implement energy performance improvement measures in their corrugated board production and conversion processes.

WORKSHOP WITH SUSTAINABLE MANUFACTURING WORKGROUP

A workshop was organized to analyze the outcomes of the EEQ and interviews, involving industry leaders and experts from the corrugated board production and conversion. The purpose of the workshop was to delve into the topics gathered from the EEQ and interviews, facilitating in-depth discussions and prioritization of measures for energy improvement within the industry.

During the workshop, the attendees had the opportunity to review and discuss the findings, insights, and recommendations derived from the EEQ and interviews. The topics covered various aspects of energy performance in corrugated board production and conversion, including equipment efficiency, process optimization, heat recovery, insulation, and other relevant areas.

The workshop provided a platform for industry leaders and experts to share their experiences, perspectives, and expertise regarding energy efficiency in the corrugated board sector. By engaging in collaborative discussions, attendees were able to collectively assess the relevance and feasibility of different measures and identify their potential impact on energy performance.

Through these discussions, the attendees worked together to prioritize the identified measures based on their perceived importance and potential for energy improvement. The prioritization process ensured that the most relevant and impactful measures received the necessary attention and consideration for implementation in the short-term perspective. The outcomes of the workshop informed the content of the handbook, ensuring that it presents the most relevant and feasible energy performance improvement practices for corrugated board production and conversion.

TOPICS IDENTIFIED AS STANDARD OR NOT BEST PRACTICE

Certain topics identified as standard practices or not mature today were excluded from the recommended best practices list. This reflects on the current state of knowledge and industry practices, i.e., these practices are already widely adopted as standard procedures or require further development and refinement before they can be considered as best practices.

By briefly discussing these excluded topics at the end of each chapter, the handbook provides readers with a well-rounded understanding of energy reduction potential in a corrugated board and conversion processes. This approach acknowledges the evolving nature of the industry and encourages ongoing research and improvement in those areas.

STEAM GENERATION AND DISTRIBUTION

Steam is widely used in corrugated board production and conversion because it is an efficient heat carrier. Steam gives up its heat energy to various processes involved in corrugated board production. The steam used in a corrugator machine serves multiple purposes. It helps condition the paper, making it more pliable for corrugation. The steam heat softens the fibers, allowing them to be molded into the desired shape. Additionally, steam provides the necessary heat for activating the adhesive and achieving a strong bond between the liner and fluting.

High-quality dry saturated steam is essential for maintaining accurate temperature control and efficient heat transfer. Saturated steam is used because its temperature is directly related to its pressure. By controlling the pressure of the steam, the temperature of the heated components can be accurately controlled. Any moisture or incondensable gases present in the steam can lower its temperature and impair heat transfer rates. This can make temperature control difficult and may hinder the achievement of desired production temperatures.

Modern high-speed corrugators often require steam at temperatures up to 190°C and pressures between 12 and 16 bar to meet the demands of the process, Fig. 4. These specific operating conditions ensure optimal performance and efficient production.

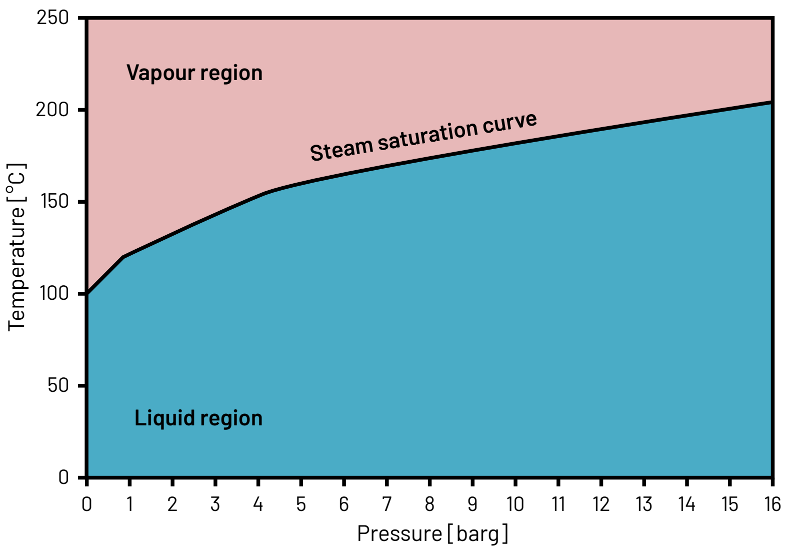


Fig. 4 Steam saturation curve

STEAM BOILER

The steam boiler used in corrugated board manufacturing is typically operated at steam pressures in the range 12–16 barg. It is usually fueled by natural gas (90-95%) or oil, and its heat output is controlled to maintain correct temperature and moisture level during the corrugation process. Thus, regular maintenance and inspection of the steam boiler is essential to ensure safe and efficient operation as well as to minimize downtime and reduce the risk of accidents.

Most of the boilers in operation within the corrugated board industry today have steam production capacity range 5–10 ton/h. Typical energy losses from boiler occur by radiation and convection through boiler walls (2–4%), heat losses with exhaust gases (14%) and blowdown (1–3%) (Parr, 2021). An energy Sankey diagram for a typical natural gas fired steam boiler in the context of corrugated board production and conversion industry is shown in Fig. 5.

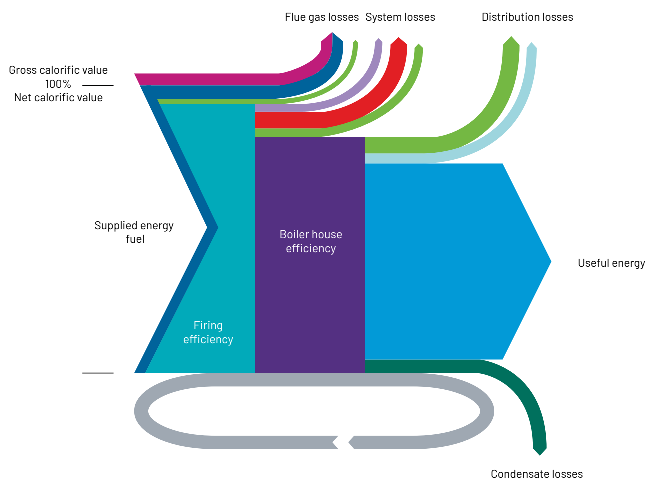


***Fig. 5 Energy Sankey diagram for a typical gas fired steam boiler including steam distribution and condensate system** (Source: Bosch planning tool for steam boiler systems)*

Subsections p. 17 and 19 present the best practices identified for improved boiler performance.

Link to EEQ results for steam generation Fig. S 1 EEQ results – Steam Generation

Burner and exhaust gas system

Reduce exhaust gas losses by burner control

Reduce exhaust gas energy losses through regular measurement of oxygen (O2) or carbon monoxide (CO) in the exhaust gases to ensure burner operation in the maximum efficiency range. Typically, without O2 and CO control, excess air is set at 3-4% by volume of oxygen in the flue gas at full load. However, with the implementation of O2 and CO control, this excess air setting can be reduced to 0.5-1.0% by volume of oxygen, Fig. 6. This leads to a reduction in flue gas losses, resulting in better energy efficiency.

This measure is a common practice with about 70% of the surveyed plants implementing some form of a control mechanism. Moreover, interviews with boiler suppliers indicated about 1% fuel saving can be achieve through implementation of this measure.

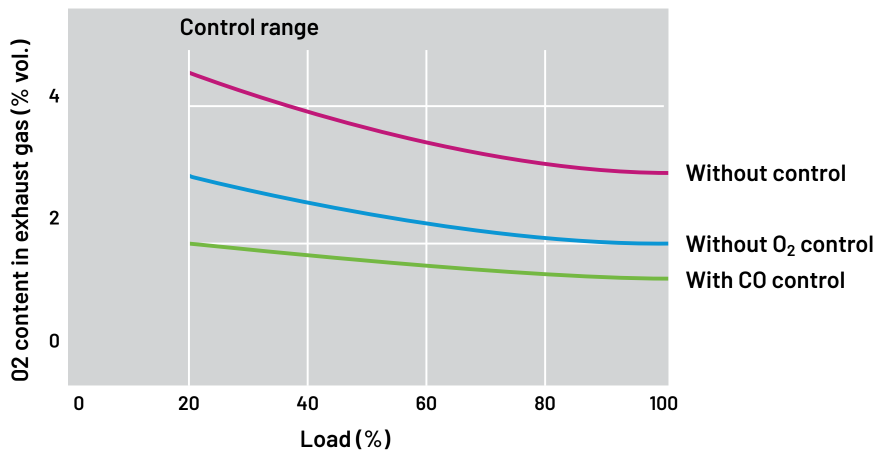


Fig. 6 Residual oxygen content and excess air using O2 and CO control via the burner load ***(Source: Bosch planning tool for steam boiler systems)***

Install burner fan speed control

Burner fan speed control refers to the regulation and adjustment of the speed of a fan used in a burner system. Burner fans are commonly found in various applications, such as in furnaces, boilers, and industrial burners, where they play a crucial role in providing the required air or oxygen supply for combustion. Controlling the fan speed in a boiler system is important for achieving optimal combustion efficiency, maintaining flame stability, and controlling pollutant emissions. A Variable Frequency Drive (VFD) can be installed to control the speed of the fan motor. By adjusting the voltage and frequency supplied to the motor, a VFD allows for precise control of the fan speed. This method offers more flexibility in matching the fan speed to the burner's requirements and adjusting it in response to changing conditions or process demands.

While there is a general correlation between fan speed and power consumption, the specific relationship can vary depending on the fan's design, motor efficiency, and control method. In general, variable drive fans allow operation in low-power mode leading to significant power saving. An interview with a steam system supplier indicated as high as 75% of electricity reduction can be realized compared to fixed speed fans. A workshop with industry experts emphasized that the saving is also dependent on boiler load.

Use of variable speed fan is rather a common practice covering nearly 60% of the surveyed plants. This measure is highly recommended for new installations.

Implement exhaust gas energy recovery

Economiser and additional heat exchangers

An economiser is a heat exchanger commonly used in boilers and power plants to recover waste heat from the exhaust gases and transfer it to the boiler feedwater. Its primary purpose is to improve the overall thermal efficiency of the system by preheating the feedwater and reducing fuel consumption. Most of the heat losses from a boiler occur through the exhaust gas that exit the boiler at elevated temperatures. By recovering and utilizing waste heat, the economizer reduces the energy lost through exhaust gas emissions.

The extent of heat recovery in an economiser depends on the condensate return temperature, which in turn is controlled by the pressure of the Condensate Recovery Unit (CRU). The CRU pressure is rather high in the corrugated industry and puts a limitation on the extent of heat recovery in an economiser. In industries, such as pulp and paper mill the condensate is recovered at pressures low-enough that allow efficient recovery of the thermal energy in exhaust gas for boiler feedwater preheating. In this regard, other application areas such combustion air preheating and space heating should be considered to enable full utilization of exhaust gas energy.

For example, higher supply temperature of combustion air improves the combustion or firing efficiency. Fig. 7 shows natural gas combustion efficiency against temperature difference between exhaust gas and combustion air supply evaluated using the Siegert equation(Bosch, 2023). The curves are plotted for a range of lambda (λ-excess air factor) or the corresponding O2 content in exhaust gas. Accordingly, maintaining maximum possible supply air temperature to a burner by exchanging heat with exhaust gas is a good practice to improve the overall performance of a steam boiler.

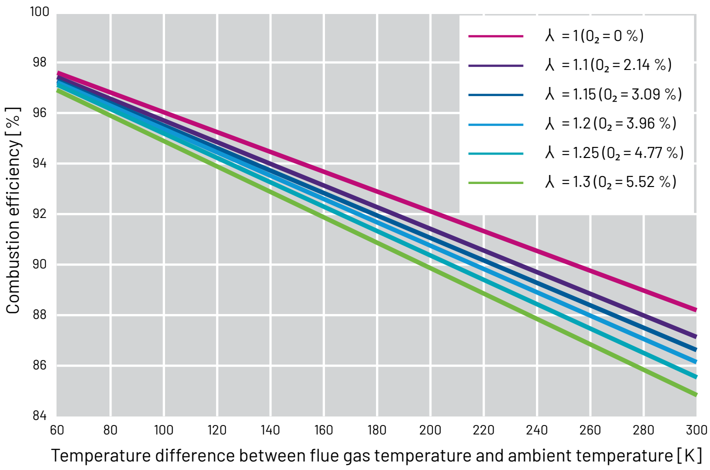


Fig. 7 Natural gas combustion efficiency vs. ΔT–exhaust gas and supply air temperature difference over a range of λ (excess air factor) or the corresponding % vol. O2 content in flue gas (Source: Bosch planning tool for steam boiler systems)

Boiler feedwater treatment

Depending on the location of a plant, the quality of fresh water varies considerably. Boiler feedwater should meet certain specs for smooth operation, reduce desalting rates and minimize blowdown steam.

Use reverse osmosis for water pretreatment

Reverse osmosis (RO) is commonly used as a pretreatment method for boiler water to remove impurities and ensure the production of high-quality feedwater. By employing RO in the boiler water pretreatment process, it helps prevent scaling, corrosion, and other issues that can adversely affect boiler performance and efficiency. In RO process, prefiltered water is pressurized and forced through semi-permeable membranes that have very tiny pores. These membranes allow water molecules to pass through while rejecting dissolved salts, minerals, organic compounds, and other contaminants. As a result, purified water, known as permeate, is obtained, while the rejected impurities are discharged as concentrate or brine.

Continuous monitoring of the RO system's performance is essential to ensure its effectiveness. Parameters such as pressure, flow rates, and water quality are monitored to identify any deviations or changes in the system's performance. Adjustments can be made to operating conditions, such as pressure and recovery rates, to optimize the RO process for the specific feedwater characteristics.

Interviews with steam system suppliers and a workshop with experts from the corrugated industry identified RO as one of the least energy intensive and very effective feedwater pretreatment techniques. The increase of efficiency is achieved by the decrease of water conductivity in the boiler which leads to a less amount of sluice.

Install automatic water conductivity control sluices

The primary purpose of a conductivity control sluice is to manage the concentration of dissolved salts or minerals in the water, thereby maintaining an optimal conductivity level for the intended application. By adjusting the conductivity, users can ensure that the water meets specific quality requirements or is suitable for boiler feedwater. Advanced conductivity control sluices are typically equipped with automation and control systems that use the conductivity measurements as input. These systems can automatically adjust the sluice's gates, valves, or other components to maintain the desired conductivity level without manual intervention.

Automatic control sluices provide several benefits that contribute to improved efficiency and resource conservation. The benefits of automatic control sluices include reduced energy loss, reduced freshwater demand, reduced load on wastewater treatment and improved boiler operation. Regular control and monitoring of the automatic sluice's performance, particularly through the control of fresh feedwater, are indeed crucial to achieving the best outcomes. This includes periodic inspections, calibration checks, and performance evaluations. By proactively managing the automatic sluice's performance, you can identify and address any issues promptly, ensuring its continued effectiveness in reducing blowdown and optimizing boiler efficiency.

An interview with a technology supplier indicated that the implementation of this measure alone can achieve about 1% fuel saving.

STEAM AND CONDENSATE SYSTEM

The condensate system is an essential component of the corrugating process that helps to manage the steam and condensate generated during the corrugating process. As steam is used to heat and moisten the paper, it is transformed into condensate that must be collected and removed from the system to ensure proper operation.

The steam and condensate system typically consists of the following components:

- Steam pipes: Steam pipes are part of a distribution system that transports steam from the boiler to different parts of the corrugator machine. The steam is typically carried at high pressure to ensure efficient heat transfer.
- Condensate tanks: The condensate tanks are used to collect and store the condensate generated during the corrugating process. The tanks are usually located at the bottom of the corrugator and are designed to handle high volumes of condensate.
- Condensate pumps: The condensate pumps are used to transport the condensate from the corrugator to the boiler for reuse. The pumps are typically electric-powered and are designed to handle high volumes of condensate.
- Condensate pipes: The condensate pipes are used to transport the condensate from the corrugator to the boiler. The lines are usually made of stainless steel or other corrosion-resistant materials and are designed to handle high temperatures and pressures.
- Steam traps: The steam traps are used to remove condensate and non-condensable gases from the steam system without letting steam escape. The traps are usually located at low points in the system, where the condensate collects and can be removed.

Energy efficiency measures related to steam and condensate system are presented in the following text.

Insulate the entire steam and condensate system

Insulating the entire steam and condensate system is important for maintaining high efficiency of the system, minimizing energy losses and ensuring the safety of personal working in the surrounding. The importance of this measure is well perceived across the industry with implementation rate over 95% of the plants responded to the questionnaire.

Interviews with steam system suppliers further elaborated the need for regular checks for inefficient and damaged insulation followed by immediate remedy. Neglect and lack of immediate action could forfeit as much as 8% of fuel saving.

Using a closed loop steam and condensate system: maximize closed loop, recover condensate in a high-pressure tank

By using a closed-loop steam and condensate system, maximizing condensate recovery, and storing the condensate in a high-pressure tank, reduce energy consumption in the corrugator, Fig. 8. This approach helps utilize the heat energy contained in the condensate and minimizes the need for continuous steam generation, resulting in substantial energy savings and improved sustainability.

Nearly all corrugators in Europe have implemented closed loop steam and condensate system. The survey showed about 80% of the plants have implemented this measure with additional 9% planning to act shortly. Interviews with technology suppliers indicate as much as 12% fuel saving can be achieved compared to open loop steam and condensate system.

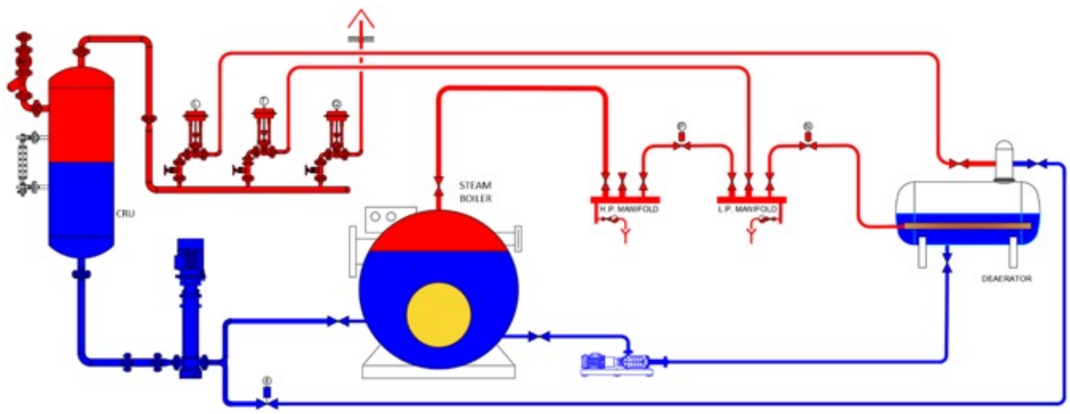


Fig. 8 Closed loop steam and condensate system – configuration with a high-pressure CRU (Source: Baviera Steam Systems 2023)

Use a cascade system for steam utilization in series

Applying a cascade system for steam utilization in series allows for efficient energy transfer from high-pressure to low-pressure processes. A cascade system involves utilizing steam at different pressure levels in a sequential manner to maximize energy utilization. Proper system design, monitoring, and optimization are crucial to achieving the desired energy efficiency in the corrugation process.

Identify different pressure levels of steam required for various processes in the corrugation line. For example, high-pressure steam may be needed for preheating, medium-pressure steam for corrugating rolls, and low-pressure steam for drying. Generate steam at the highest pressure level required for any process in the corrugation line. Distribute the high-pressure steam to the processes that require it directly. After the high-pressure steam is utilized for the first process, implement a pressure reduction system to decrease the steam pressure to the next required level. This can be achieved through pressure reduction valves or steam pressure control devices.

Implement condensate recovery systems at each pressure level to collect and reuse the condensed steam. This helps maximize energy utilization by recycling the heat energy contained in the condensate.

The survey showed nearly 45% have implemented this measure in some form with additional 27% planning to act in the short term. The workshop stressed that the success of this measure is strongly linked to the individual plant layout.

Perform regular checks on the steam and condensate system including insulation, steam leaks, condensate traps and implement corrective actions immediate after

Proper operation and maintenance of the steam and condensate system ensures safe and efficient operation of the corrugating process. The condensate tanks, pumps, and pipes must be regularly inspected and maintained to prevent leaks, blockages, and other issues that can lead to downtime and equipment failure. The steam traps must also be regularly inspected and replaced to ensure proper operation and prevent damage to the steam components.

According to the survey 62% of the plants perform audits on steam and condensate system with additional 18% planning to act in the short term. Discussion during the workshop highlighted the need to involve skilled specialists for successful implementation this measure. Moreover, 92% of the surveyed plants indicated that they conduct regular checks for issues about insulation, steam leaks and condensate traps, with the the remaining 7% indicating plans to act.

Monitor the amount of fresh feedwater to the boiler

Interview with steam system suppliers indicated that monitoring the amount of fresh feedwater to the boiler is a good practice and very cheap to implement. Most deviations within the steam and condensate system can be detected by just monitoring fresh feedwater. Even though pinpointing the exact cause would require installation of additional monitoring devices along the steam and condensate lines.

Ensure dry steam (slightly superheated) before corrugator

It is highly recommended that the steam before corrugator be slightly superheated to avoid unnecessary and often detrimental condensation on paper surfaces. Thus, the degree of superheat at the boiler outlet must be high enough to overcome losses and maintain the steam quality required before the corrugator.

Monitor and remedy inefficient or damaged insulation

Monitoring and remedying inefficient or damaged insulation in the corrugator is essential for maintaining high energy efficiency.

Conduct regular inspections of the insulation throughout the corrugator machine. Inspect steam pipes, tanks, preheaters, dryers, and other components where insulation is present. Look for signs of damage, deterioration, or gaps in insulation coverage. Use thermographic imaging techniques to detect areas of heat loss or insulation inefficiencies. Infrared cameras can help identify temperature variations and pinpoint locations with inadequate insulation or insulation damage. Perform thermographic inspections periodically to assess the condition of the insulation.

An interview with a technology supplier indicated as much as 8% fuel saving can be realized through regular monitoring for damaged insulation followed by immediate remedy.

Synchronize operational time of the boiler and the corrugator

Synchronizing the operation of the boiler and the corrugator avoids stand-by losses. When the boiler and corrugator work together harmoniously, it ensures a consistent and reliable supply of steam to the various components involved in the corrugation process.

Install automatic control on steam to hotplates, single facer & double backer

Installing automatic control devices on the steam flow to the hotplates, single facer, and double backer is a recommended practice. These control devices, such as flow meters and control valves, enable precise regulation of steam supply to different sections of the corrugator. Such devices can help minimize energy losses during extended standby periods.

ADDITIONAL PRACTICES RELATED TO STEAM GENERATION AND DISTRIBUTION

The following measures were either part of the EEQ or added after the interviews but deemed standard practice or not best practice during the workshop.

Use a closed loop steam and condensate system

This measure is a standard practice. Nearly all corrugators in Europe have shifted to closed loop steam and condensate system. In addition to the enhanced process control, closed loop system saves energy corresponding to as much as 12% fuel to the boiler compared to open systems.

Exhaust gas condenser

The exhaust gas often exits a non-condensing economiser at temperatures higher than the dew point, which for natural gas combustion products falls in the range 55-65°C depending on the composition and operating conditions. A condensing heat exchanger can exploit the latent heat of the exhaust gas for low-temperature applications such as space heating or exported to a nearby facility.

Interviews with technology suppliers indicate as much as 2.5% fuel saving can be achieved by implementing exhaust gas condenser for low-temperature applications previously supplied with steam.

BEST PRACTICES INDEX: STEAM GENERATION AND DISTRIBUTION

Steam generation and distribution

CORRUGATING

CORRUGATOR

Corrugating transforms separate paper webs into a single, rigid board with fluted middle layers. Corrugated board serves as a versatile material for packaging applications, providing strength, cushioning, and structural support to protect and transport various goods.

A corrugator consists of several components that work together to produce the final product. The main units of a corrugator are divided into a wet end and a dry end. The wet end consists of reel stands, splicers, preheaters, preconditioners, single facers (which contain corrugating rolls and the single facer glue unit), the bridge, the double facer as well as its glue unit.

The single face corrugated board (a fluting glued to a liner), that is produced in the single facer, is transported in loops on a bridge. Glue is then applied again to the open flute of the single faced board in the glue unit of the double facer before it is pressed together with the outer liner in the double facer to form corrugated board. Therefore, the now rigid corrugated board is heated and the glue is dried. To produce double or triple corrugated board, two or three single face corrugated board webs are glued together and dried in the double facer.

After the double facer, the corrugated board is entering the dry end of the corrugator. Here the corrugated board is transported through the rotary shear at first. The rotary shear can be used to remove faulty material from the wet end, or to cut the web completely when changing format or job. The slitter scorer cuts the corrugated board lengthwise and grooves it where it shall be folded in converting. Followed by the slitter scorer is the cutoff, where the endless corrugated board web is cut to the demanded length. The cut sheets are then stacked in the automated stacker (see Fig. 9).

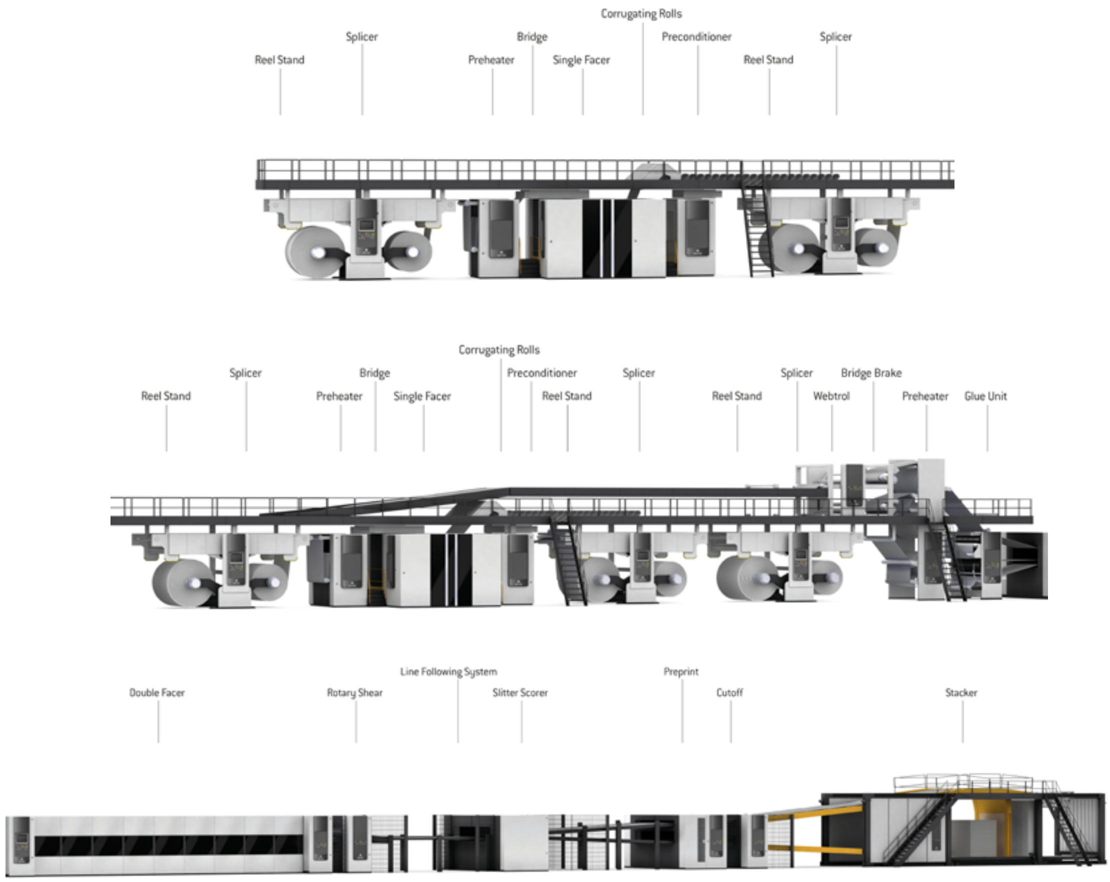


***Fig. 9 Corrugated board production process in a corrugator** (Source: BHS Corrugated 2023)*

The stack can then be further processed, such as undergoing printing, die-cutting, and folding to create various packaging products like boxes, cartons, or displays.

Good practice measures for improving energy performance of a corrugator are presented in the following text.

Link to EEQ results for corrugating Fig. S 2 EEQ results - Corrugating

Reduce steam pressure on the corrugator preheaters

The primary purpose of preheaters is to raise the temperature of the liner and medium to the desired level before they are fed into the corrugating rolls. Heating the paper softens the fibers, making them more pliable and receptive to the corrugation process. This leads to improved bonding between the liner and fluting, resulting in a stronger and more stable corrugated board.

Steam preheaters are the most widely used designs in the corrugated industry. To promote energy efficiency and minimize energy consumption, it is recommended to maintain the steam pressure for preheating as low as possible, with a target not exceeding 10 bar.

The survey showed about 65% of plants already maintain the preheating steam pressure less than 10 bar.

Moreover, industry experts are in consensus with the usefulness of this measure as energy saving practice for corrugated board manufactures.

Install temperature sensors at the exit of the preheaters and use a closed loop wrap arm control system

By implementing temperature sensors and a closed loop wrap arm control system, improve energy efficiency in the corrugating process. With accurate temperature control and wrap arm adjustments, the closed-loop control system helps to optimize the use of heat in the preheating process. This means that the energy used for heating can be precisely regulated, reducing unnecessary energy consumption.

The closed loop wrap arm control system uses the temperature sensor data to make real-time adjustments to the wrap arms. This system can be seen as a predecessor of the process control system.

Installation of temperature sensors at the exit of preheaters and implementation of a closed loop wrap arms control system has been discussed as a best practice measure in the survey and during the workshop with experts. Over 50% of the surveyed plants have implemented this measure and an additional 20% indicated plans for installing the system in the short term.

Run as cool as possible on the corrugator

Running a corrugator at the coolest possible temperature can indeed help minimize energy use. By focusing on process optimization, insulation, heat recovery, efficient equipment, maintenance, monitoring, and training, run the corrugator at the lowest possible temperature while maintaining product quality and achieving significant energy savings. However, it's crucial to strike a balance between energy reduction and ensuring that the final product meets the required quality standards.

Interview with technology suppliers highlighted that the measure is in line with energy optimized corrugating principles formerly known as 'cooler corrugating'. Moreover, the workshop with experts confirmed that the importance of this measure is well recognised by industry.

Use process control system at the corrugator

The consensus about the need for process control at the corrugator is nearly unanimous. Survey respondents, industry experts and technology suppliers agree that certain level of process control is crucial for ensuring consistent product quality, maximizing efficiency, and minimizing waste. The results from the survey were that already more than 50% of the plants have installed process control systems while another 30% are planning to install them. Here are some key aspects of process control in corrugator operations related to energy efficiency:

Control by temperature
Accurate temperature control is essential throughout the corrugator process. Various components, such as the preheaters, glue unit, hot plates, and drying sections, require precise temperature regulation to achieve optimal bonding and drying of the corrugated board. Temperature sensors and control systems are used to monitor and adjust the temperature settings as needed.

Control by moisture
Controlling moisture levels is critical for maintaining dimensional stability and preventing warping or delamination of the corrugated board. Moisture content is monitored and controlled at various stages, such as the preheating, conditioning, and drying sections. Sensors and feedback loops help maintain the desired moisture levels for consistent board quality.

Interviews with industry experts and technology suppliers also highlighted the importance of moisture control as a good practice. While temperature monitoring is straightforward and accurately measurable, monitoring moisture poses additional challenges due to its inherent complexities and dependencies on other conditions such as moisture migration, temperature and so on. Still moisture control is not as wide spread as temperature control in the corrugated board industry but measuring techniques for moisture as eg microwave or NIR (Near infrared) technology are evolving.

Control by warp (closed loop)
Warp of the corrugated board sheets can be measured automatically at the end of the corrugator. Measurement systems can be based eg on cameras or lasers. The information on warp of the corrugated board sheets is then used to change the set-points for temperature (as control by temperature) or moisture (as control by moisture).

Use peripherical heated corrugating rolls and hot plates

Utilizing peripheral heated corrugating rolls and hot plates can help improve the efficiency and performance of a corrugator. Benefits of peripheral heated corrugating rolls and hot plates include:

- Energy efficiency: By applying heat directly to specific areas, peripheral heated corrugating rolls and hot plates minimize energy wastage and improve overall energy efficiency.
- Improved bonding: The controlled heat provided by peripheral heated corrugating rolls and hot plates ensures better bonding between the liner and medium, resulting in stronger and more consistent corrugated board.
- Enhanced production speed: The application of localized heat promotes faster drying and curing of adhesives, allowing for increased production speed and shorter drying times.
- Consistent quality: The regulated temperature control offered by these components helps maintain consistent quality throughout the corrugation process, reducing variations and improving product uniformity.

The survey shows about 70% of the plants have implemented this measure and an additional 30% plan for implementation in the short term.

Study the impact of the double facer belt on energy consumption

The double facer section of a corrugator involves the lamination of the corrugated medium with the liner sheets using heat and pressure. Establish baseline for analyzing energy consumption related to the belt of the doublebacker. This may include steam usage for heating the belt, electrical power for driving the belt motor, and auxiliary equipment associated with the belt.

Based on analysis of energy data and belt performance, identify potential areas for optimization. This may involve adjusting belt tension, optimizing steam pressure and temperature settings, or exploring energy-efficient belt materials. Consult with equipment manufacturers or industry experts for guidance on energy-saving measures specific to your double facer setup.

An interview with a technology supplier indicated 20%–25% electricity consumption of the double facer drive can be saved by switching to a specialized belt.

Monitor and report specific energy consumption of the corrugator on a regular basis

Regular monitoring of energy use in the corrugator has been identified as a good practice for improving energy performance of the corrugator. Accurate monitoring of steam consumption may not be straightforward, but other indicators such as natural gas consumption in the boiler can be used as an indirect indicator.

Analyze the collected data to identify patterns and trends in steam (natural gas) consumption.

Look for any deviations from expected energy usage and act immediately to remedy any discrepancy.

Establish benchmarks or target values for specific energy consumption based on historical data or industry standards. These benchmarks can serve as a reference for evaluating the efficiency of energy usage.

Identify areas of high consumption or inefficiencies in the corrugator process. This may include excessive energy usage during start-ups, inefficient distribution, or equipment malfunctions. Investigate the causes of high consumption and explore potential optimization measures.

The survey shows over 80% of plants have implemented measures to regularly monitor energy consumption of the corrugator and an additional 17% indicated plans to act shortly.

Reduce steam pressure while corrugator on stand-by operation

Reducing steam pressure during stand-by operation on a corrugator can help conserve energy and improve efficiency.

Identify the specific periods when the corrugator is in stand-by mode, such as during breaks, shift changes, or scheduled downtime. Analyze the duration and frequency of these stand-by periods to determine the potential energy-saving opportunities.

Evaluate the minimum steam pressure required to maintain essential functions during stand-by operation. Consult equipment manuals or work with the corrugator manufacturer to identify the appropriate pressure levels for different components or processes.

Install pressure control devices, such as pressure regulators or control valves, in the steam supply system. These devices allow you to adjust and maintain the desired steam pressure levels during stand-by operation. Ensure they are properly sized, installed, and calibrated. Explore the possibility of implementing automated control systems that can adjust steam pressure based on pre-set parameters or occupancy sensors. These systems can automatically lower the steam pressure during stand-by periods and restore it when the corrugator resumes operation. Adjust the pressure control devices to reduce steam pressure to the minimum required level during stand-by periods. This helps prevent excess steam consumption and associated energy waste.

Train operators and maintenance personnel on the importance of steam pressure reduction during stand-by periods. Provide them with clear instructions on adjusting the pressure control devices and monitoring steam pressure to maintain efficiency. Reducing steam pressure during stand-by operation requires a balance between energy conservation and maintaining operational readiness. Collaboration between production personnel, maintenance teams, and energy management personnel is crucial to guarantee effective implementation and ongoing optimization.

Clean the hot plates of the double facer on a regular basis

Regularly cleaning the hot plates of the double facer helps maintain optimal heat transfer, prevents adhesive buildup, and improves the overall performance of the corrugator.

Coordinate cleaning of hot plates with production schedule to minimize disruption. Develop a maintenance schedule that includes regular cleaning of the hot plates during planned downtime, or planned maintenance activities. This ensures that cleaning does not impact production timelines. Consider the production volume, adhesive type, and manufacturer recommendations when determining the frequency of cleaning.

A technology supplier initially recommended this measure, and later it was confirmed as a good practice during the workshop conducted with expertise from the industry.

Ensure correct web tension for optimum heat transfer

Correct web tension is crucial for achieving optimum heat transfer on a corrugator. Operators should be trained to understand the recommended tension range and able to adjust to maintain the correct web tension. Consult with the equipment manufacturer's guidelines or recommendations to determine the appropriate web tension for a specific corrugator setup. Factors such as board type, speed, and adhesive application requirements can influence the recommended tension range.

Regularly monitor the web tension during production runs. Use tension sensors or tension monitoring systems to measure and display the tension levels accurately. Continuously observe the tension variations and adjust as needed to keep the tension within the recommended range.

Reduce/optimize the use of spray steam

Reducing and optimizing the use of spray steam in the corrugation process improves energy efficiency and minimize water consumption. Conduct a thorough evaluation to identify areas where spray steam is being used and determine if it is necessary or if alternative methods can be employed. Look for opportunities to minimize or eliminate spray steam usage without compromising the quality of the final product.

Use appropriate nozzles or spray patterns to target the specific areas that require moisture, reducing overspray and water wastage. Ensure that steam is applied only where and when it is needed, minimizing excess usage.

Explore alternative sources of moisture that can replace or supplement the use of spray steam. For example, consider using pre-conditioned or pre-moistened linerboard with water films to reduce the reliance on spray steam for moisture during the corrugation process. This can help minimize energy consumption associated with steam generation.

Use control valves for separate heating cylinders of the preheater

By using control valves for separate heating cylinders in the preheater, you can achieve better temperature control, improve energy efficiency, and enhance the overall performance of the corrugator. The ability to adjust the temperature individually for each cylinder allows for precise control and optimization of the heating process. Regular monitoring, calibration, and maintenance are essential for ensuring the effective operation of the control valves and the preheater system.

Install control valves on the supply lines of each heating cylinder in the preheater. These valves allow for individual control of the steam or heating medium flow to each cylinder. Connect the control valves to a central control system that allows for independent temperature regulation of each cylinder. This system can include temperature sensors, actuators, and controllers to monitor and adjust the steam or heating medium flow based on the desired temperature settings.

A technology supplier recommended this measure, and later was confirmed as a good practice during the workshop with experts from the industry.

Evaluate heat recovery from the cabinets of the single facers

Estimate the heat recovery potential from the cabinets by calculating the heat dissipation rate and the duration of the production runs. Use temperature sensors or thermal imaging techniques to measure the heat dissipated by the identified sources. Record the temperature readings at regular intervals during production runs to understand the heat output patterns.

Investigate and evaluate heat recovery technologies suitable for capturing and utilizing the recovered heat. Some options include heat exchangers, heat pumps, or air-to-air heat recovery systems. Consider the feasibility, cost-effectiveness, and compatibility with the corrugator's operations and infrastructure.

Reduce waste

Reducing waste is a key strategy to improve corrugator energy and resources use. By minimizing waste, the overall performance is improved. Review raw material usage and identify opportunities to reduce waste. This may include optimizing roll sizes, improving cutting precision, and minimizing trim waste. Proper planning and accurate measurements can help reduce material waste and the associated energy required for production. Enhance quality control processes to minimize product defects and reject rates. By improving product quality, reduce waste and avoid rework or scrap, which can consume additional energy resources.

Train employees on waste reduction techniques and encourage them to actively participate in waste reduction initiatives. Engage them in identifying opportunities for improvement and empower them to suggest innovative ideas to minimize waste and improve energy efficiency.

By focusing on waste reduction, improve energy efficiency, reduce resource consumption, and enhance the sustainability of corrugator operations. Regular monitoring, continuous improvement, and collaboration across teams and stakeholders will be essential for successful waste reduction.

Reduce start/shutdown (grade change) downtimes and increase corrugator output

Reducing start/shutdown downtimes and increasing corrugator output can help improve efficiency and productivity. The survey shows about 70% of the plants have somehow implemented measures to reduce grade change downtimes. Some aspects of good practice measures towards achieving the goal discussed in the survey as well as during the workshop with experts are presented in the following text.

Develop standardized procedures for start-ups, shutdowns, and grade changes. Clearly document the steps involved, including equipment settings, material preparation, and personnel responsibilities. Train operators on these procedures to ensure consistency and efficiency.

Identify tasks that can be performed simultaneously during downtime. For example, while one job is running, operators can start preparing for the next job. This can include preheating equipment, staging materials, or performing routine maintenance tasks. Efficiently utilizing downtime can reduce overall changeover time.

Cross-train operators to perform multiple tasks and operate different sections of the corrugator. This enables flexibility and allows operators to assist in different areas during changeovers or downtime, minimizing bottlenecks and downtime delays.

Implement a robust preventive maintenance program to ensure the corrugator is running optimally. Regularly inspect and maintain equipment to prevent unexpected breakdowns and minimize downtime. Schedule maintenance tasks during planned downtime to avoid disrupting production.

Utilize real-time monitoring systems to track machine performance, identify bottlenecks, and detect potential issues. This can include monitoring equipment parameters, production rates, and quality metrics. Timely identification of problems allows for prompt resolution and minimizes downtime.

Foster a culture of engagement and ownership among employees. Encourage them to take responsibility for optimizing production and reducing downtime. Recognize and reward employees for their contributions to improving efficiency and increasing output.

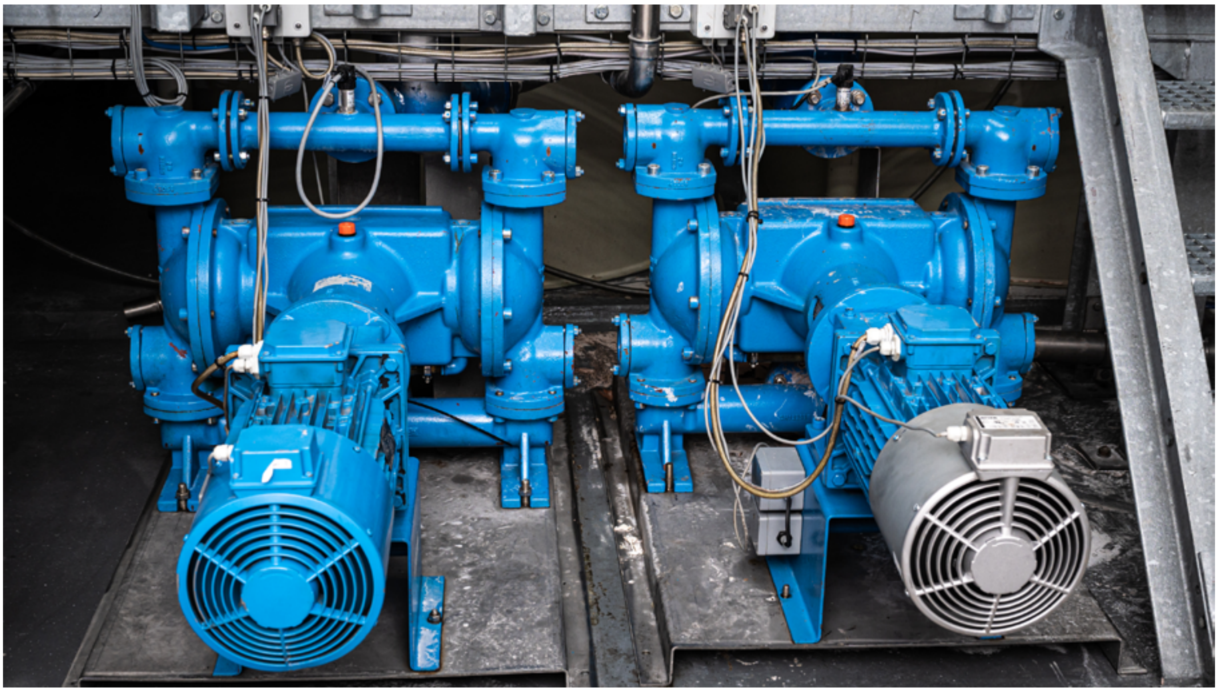
Collect and analyze data related to downtime, changeover times, and production rates. Identify patterns and areas of improvement based on data analysis. Use this information to drive decision-making and implement targeted improvements.

Study the influence of the loading system on the heating plates on steam and electricity consumption

To study the influence of the loading system on steam and electricity consumption in a corrugator machine, collect data on energy usage due to loading speeds, plate designs, and insulation conditions. Compare the data to identify patterns and determine the impact of each factor on energy consumption. This analysis can guide you in optimizing the loading system to reduce steam and electricity consumption in the corrugator machine.

The rate at which corrugated board is loaded onto the heating plates can influence energy consumption. Higher corrugator speeds may require more steam and electricity to maintain the desired temperature. Evaluate the loading speed and control mechanisms to identify opportunities for optimizing energy consumption.

GLUE SYSTEM



The glue system is responsible for the preparation, supply and application of starch-based glue in a corrugator. Glue is applied to fluting medium to bond it to a linerboard. A typical glue system contains a glue kitchen with glue tanks, glue pipes, glue pans, glue application rolls and doctor rolls.

In the glue kitchen, glue is prepared by mixing starch with water and other essential additives and stored in a tank. The it is then pumped to the glue unit, the glue application roll takes up the glue and the glue amount on the application roll is regulated by a doctor roll (metering roll). A schematic diagram of a typical glue system is shown in Fig. 10. The distance between the application roll and the doctor roll is the so-called glue gap. The application roll applies the adhesive to the tips of the fluting medium as it passes through the single facer. The liner gets in contact with the fluted medium, which is still supported by the corrugated roll, through a pressure roll or pressure belt. The now formed single face corrugated board, consisting of a bonded liner and fluting is then transported to the bridge. The single face board is then further transported to the glue unit of the double facer. Here the outer liner is glued to the single face board.

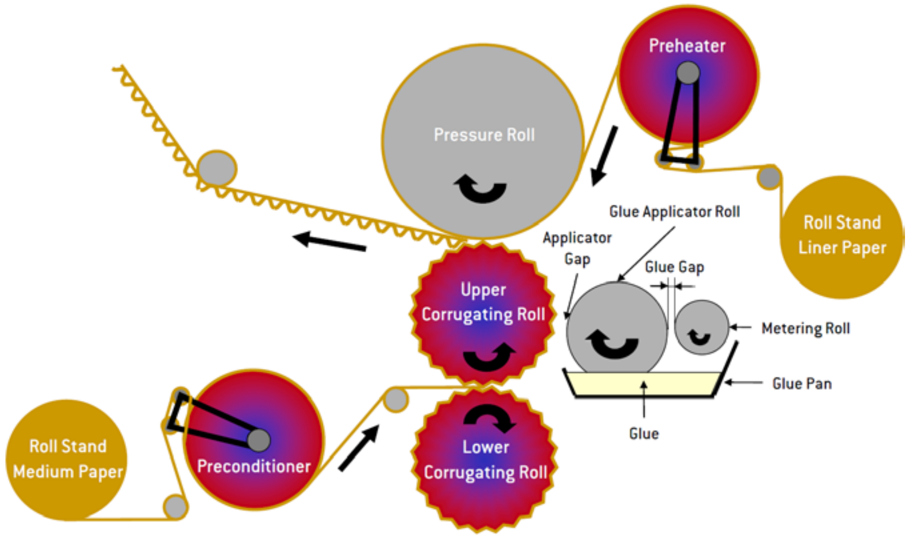


Fig. 10 Glue application system *(Source: BHS Corrugated)*

Energy efficiency measures related to a typical glue system in a corrugator are presented in the following text.

Minimize glue use by investigating and optimizing glue gap control system

Glue gap control in a corrugator refers to the management and regulation of the distance between the glue application role and the doctor role. It plays a vital role in achieving consistent and efficient bonding between the layers of the corrugated board. The gap determines the amount of adhesive applied to the tips of the fluting. The glue gap can be adjusted using mechanisms such as handwheels, knobs, or digital controls to achieve the desired glue coverage and distribution.

To ensure efficient glue gap control, various optimization techniques can be employed to minimize energy used for drying. These techniques include:

Monitoring and maintaining consistent glue viscosity

The viscosity of the adhesive affects its flow and distribution. Regularly measuring and adjusting the viscosity ensures consistent glue application. Interview with a supplier highlighted the usefulness of this measure as a good practice.

Calibrating and aligning the glue applicator

Proper calibration and alignment of the glue applicator components, such as the glue rolls and glue dams, help ensure accurate and uniform glue distribution.

Moreover, experts from the industry suggest regular cleaning of the glue rolls as good practice. Cleaning glue rolls in a corrugator is an important maintenance task that helps ensure optimal glue application and prevent issues such as uneven glue distribution, build-up of dried adhesive, and contamination.

Investigate glue application rolls spec to minimize glue use

By investigating and optimizing the specifications of the glue application rolls, minimize glue use and achieve efficient glue application in the corrugation process. It is important to find the right balance between adhesive coverage and glue consumption to ensure high-quality bonding and minimize waste. Excess adhesive results in energy penalty both during glue prep and drying.

The design of the glue application rolls can significantly impact the amount of glue used.

The speed at which the glue application rolls rotate can also impact the amount of glue used. Adjust the roll speed to achieve the desired application rate while minimizing excess glue consumption. Consider the correlation between roll speed and glue flow to optimize the process.

This measure is rather a common practice with implementation rate covering 71% of the plants surveyed.

Clean the glue rolls on a regular basis

Cleaning the glue rolls on a regular basis can help achieve optimal performance and efficiency on a corrugator. Clean glue rolls allow efficient and uniform application of adhesive onto the corrugated medium. When the rolls are free from debris, buildup, or dried adhesive, they can apply the adhesive more precisely, reducing the need for excessive application. This, in turn, minimizes adhesive waste and lowers energy consumption associated with adhesive production and drying.

If the glue rolls are not cleaned regularly, adhesive residues or debris can accumulate on the rolls' surface. This would lead in the first place to non accurate glue application.

Follow proper cleaning procedures recommended by the glue roll manufacturer to enable effective cleaning while protecting the rolls' integrity. Regularly cleaning the glue rolls as part of your maintenance routine will contribute to energy conservation and help optimize the overall energy use of your corrugator.

Run setting of the glue gap in automatic mode for precise glue application

Running the setting of the glue gap in automatic mode is a recommended approach for achieving precise glue application on a corrugator.

Determine the desired glue gap width based on the specific requirements of corrugated products. Feed these parameters into the automatic control system. Perform initial calibration of the automatic glue gap control system to establish the baseline settings. This involves setting the reference values for the desired glue gap width and ensuring the system is properly synchronized with the corrugator's operation. Consider incorporating feedback mechanisms into the automatic control system to continuously monitor and adjust the glue gap during production. This can involve sensors that measure the actual glue gap width and provide real-time feedback to the control system. The system can then make automatic adjustments to maintain the desired gap width.

Train operators on how to use and troubleshoot the automatic glue gap control system. They should understand the system's operation, parameters, and how to interpret feedback data. This will enable them to effectively monitor the glue application process and address any issues that arise.

ADDITIONAL PRACTICES RELATED TO CORRUGATOR

Additional measures discussed but deemed as standard practice or not mature today are presented below.

Use rest heat to preheat of paper reel storage to reduce steam consumption at the corrugator

Implementing a rest heat utilization system for preheating the paper reel storage area can help reduce steam consumption at the corrugator process. It harnesses the otherwise wasted heat and redirects it for useful purposes, contributing to cost savings and environmental sustainability. A challenge here could be that the rest heat contains a high level of humidity which should not be introduced to the ambient climate of the stored paper reels.

Use stored data to compare the energy consumption of similar orders and rectify deviations immediately

By leveraging stored data to compare energy consumption of similar orders and rectifying deviations immediately, enhance energy efficiency in the corrugator. This data-driven approach enables proactive energy optimization and helps identify and address inefficiencies in real-time, leading to reduced energy consumption and improved overall performance.

Establish a system to collect and store energy consumption data for different orders. This can include information such as order details, production parameters, energy usage (electricity, natural gas, etc.), and any other relevant data points.

Analyze the collected data and establish benchmarks and targets for energy consumption based on similar orders. This measure assumes that the applied software must be useable by trained corrugator staff.

BEST PRACTICES INDEX: CORRUGATING

Corrugating

CONVERTING

Converting machinery is used to convert the corrugated board into various packaging products such as boxes, trays and displays to meet the needs of various industries.

The most important converting machinery types are flexo folder gluers to produce regular slotted cases (RSC's) in a single pass and flatbed or rotary die-cutters followed by folder gluers if folding and gluing is required.

Printing is mostly performed as flexo post-print either inline as in the flexo folder gluer or inline together with a die-cutter or offline in a separate machine. Other post print processes are digital and offset printing. Also the use of already printed paper for the outer liner at the corrugator – the so called pre-print – and laminating are established processes in the industry.

Converting machines are typically connected with automation machinery as pre-feeders, bundle breakers, stackers and palletizers and are integrated into a transportation system together with the stacker of the corrugator and the storage area.

Several support processes are necessary to make the converting operations possible as the removal of the solid waste, the preparation of the inks and the removal of the coloured wastewater and the necessary systems for ventilation, vacuum transport and dust removal. Some of these support processes are of great importance for energy efficiency.

The following text summarizes best practices related to improve energy performance of converting process.

Link to EEQ results for converting Fig. S 3 EEQ results - Converting

Use a belt system for the transport of the cutting waste instead of a vacuum system with ventilators

By adopting a belt system for cutting waste transport, achieve energy savings, reduce noise levels, minimize maintenance needs, and enhance overall operational efficiency. This measure aligns with the industry's objective of improving energy performance and sustainability in the converting process. Traditionally, vacuum systems with ventilators have been employed to transport cutting waste, such as trimmings and scraps, from the cutting station to collection or disposal areas. These systems utilize suction and airflow generated by ventilators to pull the waste material through a network of pipes or ducts.

Belt systems operate through mechanical motion and eliminates the need for energy consuming ventilators, resulting in significant energy saving. Besides energy saving belt system reduce noise during operation which contributes to comfortable and quieter working environment.

Belt systems also reduce maintenance requirements. Vacuum systems with ventilators typically require regular maintenance, including filter replacements and cleaning to maintain optimal performance. In contrast, belt systems generally have simpler maintenance requirements, reducing the time and effort needed for upkeep.

Using a vacuum system with ventilators: investigate the possibility to shut down ventilators at idling of the machine(s)

Vacuum systems with ventilators are commonly used in converting plants to hold and transport corrugated board sheets during various processing stages and also for dust and waste separation. The ventilators generate suction and airflow to create a vacuum effect, which securely holds the board in place during cutting, folding, or other operations. During machine idling periods, such as when there is no board being processed or when the machine is temporarily paused, the ventilators may continue to run, consuming energy unnecessarily. Investigating the possibility of shutting down the ventilators during these idle periods can lead to energy savings without compromising production efficiency. This practice aims to optimize energy consumption by minimizing the operation of ventilators when they are not actively required for production.

The feasibility of this measure will depend on the specific characteristics of the converting equipment, the duration and frequency of idling periods, and the process requirements. Consider the following when exploring the shutdown of ventilators at machine idling:

- Idle detection: Implementing a system or mechanism that detects machine idling or non-production periods is essential. This can be achieved through sensors, timers, or integrated control systems that monitor machine activity and trigger the shutdown of ventilators accordingly.
- Operational requirements: Evaluate the impact of shutting down the ventilators on the production process. Ensure that the vacuum level necessary for holding the board securely is maintained during active production phases. Adjustments to the system's settings or operational parameters may be required to balance energy savings with production needs.
- Restart and response time: Consider the time required for the ventilators to restart and reach optimal performance when production resumes. Minimize any potential delays or disruptions in the production flow by ensuring a prompt response of the system when the ventilators are reactivated.
- Safety and equipment considerations: Assess any safety implications or equipment requirements associated with shutting down and restarting the ventilators. Ensure that safety protocols are in place to avoid potential hazards and confirm that the equipment can handle the shutdown and startup processes without adverse effects.

Check the settings of the IR dryers in printing machines. Use them only for orders where there are really required

It's essential to ensure optimal settings on the IR dryers used in printing machines and use them only when necessary.

Before starting a print job, carefully evaluate the specific requirements of an order. Determine if the use of IR dryers is truly necessary based on factors such as ink type, substrate material, and drying time.

Request operators to familiarize with the IR dryer settings available on the printing machines, particularly about temperature controls, intensity levels, and duration settings. This knowledge can enable them to make informed decisions to conserve energy.

Adjust the IR dryer settings based on the specific requirements of each print job while focusing on energy efficiency. Aim to use the minimum amount of heat and drying time necessary to achieve the desired results. Experiment with lower temperatures and shorter drying durations while monitoring print quality.

Before running full-scale production, perform test runs with different IR dryer settings to determine the optimal energy-saving configurations. Evaluate the drying effectiveness, print quality, and energy consumption during these tests.

Educate the operators responsible for running the printing machines on the importance of energy conservation. Train them to understand the impact of IR dryer settings on energy usage and encourage them to make conscious decisions to optimize energy consumption.

According to the survey, this measure is a common practice with implementation rate covering over 70% of the plants responded.

Prefer IR dryers where the modules are switched on according to the working width

IR dryers with modules that should be switched on according to the working width provide significant advantages in terms of energy efficiency, customization, drying performance, and equipment longevity.

By utilizing IR dryers with switchable modules that can be switched on based on the working width, energy consumption can be optimized. Only the necessary modules are activated, ensuring that energy is directed precisely to the areas where it is needed. This targeted approach minimizes energy waste and reduces operating costs.

Operating only the necessary dryer modules reduces the overall wear and tear on the equipment. By minimizing the usage of unnecessary modules, the lifespan of the dryers can be extended, resulting in cost savings through reduced maintenance and replacement needs.

According to the survey, this measure is a common practice with implementation rate covering over 75% of the plants responded.

Replace air pressure membrane ink pumps by electrical membrane pumps

By implementing electrical membrane pumps, ink pumping systems can optimize energy usage in several ways, including improved motor efficiency, variable speed control, reduced pressure requirements, and elimination of priming and flushing energy. Perform a thorough energy analysis of the existing ink pumping system and compare it with the projected energy consumption of the alternative pumps to determine the potential energy savings before making a decision.

Electrical membrane pumps can be more energy-efficient compared to air pressure pumps. Air compressors used to generate the air pressure for pneumatic pumps can consume a significant amount of energy. By eliminating the need for compressed air, electrical membrane pumps can reduce energy consumption and operating costs.

Replace air pressure membrane ink pumps by electrical peristaltic pumps

Replacing air pressure membrane ink pumps with electrical peristaltic pumps can offer several advantages in terms of energy efficiency, precision, and ease of use.

Peristaltic pumps are inherently energy-efficient due to their positive displacement mechanism, providing a high level of efficiency in transferring ink with minimal energy losses. Peristaltic pumps typically have lower power requirements compared to other pump types, resulting in energy savings. Peristaltic pumps eliminate the need for priming and flushing processes, which can consume additional energy in traditional pump systems.

Moreover, peristaltic pumps are versatile and can handle a wide range of ink viscosities and compositions. The flexibility of the tubing used in the pumps allows for compatibility with various ink types, including both water-based and solvent-based inks. This makes them suitable for different printing applications.

Replace hydraulic units by electric driven units

Replacing hydraulic units with electric-driven units can offer several benefits in various applications.

Electric-driven units are more energy-efficient compared to hydraulic systems, especially in applications with variable load demands. Hydraulic systems often have continuous power consumption even when not actively performing work, whereas electric-driven units can be designed to operate only when needed, minimizing energy waste.

Electric-driven units can be easily integrated into automated systems, offering flexibility in programming and seamless communication with other equipment. They can be adapted to various industrial processes and provide better compatibility with modern automation technologies. Moreover, electric-driven units offer precise control over speed, force, and motion, allowing for better accuracy and control in the converting process. This precision can improve product quality, reduce waste, and enhance overall process efficiency.

Turn off hydraulic units outside production time

Turning off hydraulic units outside production time helps to improve energy efficiency. Hydraulic units consume energy even when the machine is not in operation. By turning off the hydraulic units outside of production time, minimize energy waste and reduce overall energy consumption, leading to cost savings.

Hydraulic systems require regular maintenance and can experience wear and tear over time. By turning off the hydraulic unit during non-production hours, extend the lifespan of the system, reducing the need for frequent repairs and replacements.

When implementing this energy-saving measure, it is important to ensure that turning off the hydraulic units does not interfere with the start-up or shut-down procedures of the machine. It's recommended to follow the manufacturer's guidelines and consult with experts or technicians familiar with the specific equipment to ensure proper operation and prevent any negative impact on the machine's performance or functionality.

Recuperate the air of vacuum/ air transport systems after filtering

Air recuperation from vacuum and air transport systems after filtering can help improve energy performance of converting process. This practice aims to recover and reuse the air that is utilized in these systems, rather than allowing it to be wasted or discharged directly into the atmosphere.

Vacuum systems are commonly used in converting plants to hold and transport corrugated board sheets during various production stages and also for dust separation. These systems create suction by drawing in air, which is then used to hold the board securely in place. Similarly, air transport systems are employed to move the corrugated board between different processing stations.

By implementing air recuperation after filtering, the discharged air from these systems is captured and passed through filters to remove any contaminants or impurities. The filtered air can then be redirected back into the facility and reused in various ways, such as providing ventilation, maintaining air pressure, or even as a source of clean air for other processes.

This practice not only contributes to energy efficiency by reducing the need for fresh air intake and ventilation systems but also helps in improving air quality by filtering out any particulates or pollutants. Additionally, it can lead to cost savings by minimizing the energy required for conditioning and heating fresh air.

Implementing air recuperation after filtering may require the installation of appropriate filtration systems, ductwork, and control mechanisms to redirect and distribute the filtered air effectively. The specific design and implementation will depend on the facility's layout, equipment configuration, and production requirements.

Choose the appropriate source of drying system for drying of inks and hardening of varnish

Selecting the appropriate source of drying system for drying inks and hardening varnish can contribute to energy-efficient operations. Different drying systems have varying energy requirements and effectiveness in achieving the desired drying and hardening results.

- Infrared (IR) drying: Infrared drying systems use infrared radiation to transfer heat directly to the printed or varnished surface, promoting rapid drying and hardening (evaporating of water is taking place). IR drying is known for its quick response time and energy efficiency. It can be a suitable option for drying inks and varnishes on corrugated board, as it allows for precise control and targeted application of heat. However, it is essential to ensure proper ventilation and safety measures, as IR drying generates heat and also generates water vapour, so ventilation is necessary. There is not much energy necessary as the waterfilm (that contains the ink) which needs to be evaporated is only 1 or 2 μm. There is more water in the corrugated board, but it is not wanted to evaporate the water in the board. Therefore the IR dryer needs a control system.
- Hot air drying: Hot air drying involves circulating heated air around the printed or varnished surface to facilitate drying and hardening. This method relies on a forced air stream supporting heat transfer and is commonly used in various industries. It is effective for drying water-based inks and varnishes. Considerations should include the design and efficiency of the hot air system, insulation, air circulation, and temperature control to optimize energy usage.
    - Implement heat recovery systems to capture and repurpose waste heat generated from various processes within the production facility. This recovered heat can be directed to the drying equipment for inks and varnishes, reducing the need for additional energy sources.
    - Conduct a comprehensive evaluation of the facility's heat sources and the specific requirements of the ink and varnish drying process to determine the feasibility and effectiveness of utilizing residual heat. Collaborating with energy experts, equipment suppliers, and conducting energy audits can provide valuable insights tailored to your facility.
- Ultraviolet (UV) curing: UV curing is a popular method for the instant curing and hardening of inks and varnishes. It involves using UV light to initiate a chemical reaction that rapidly solidifies the ink or varnish. UV curing offers fast curing times, reduced energy consumption, and eliminates the need for solvent evaporation. However, it requires the use of UV-curable inks and varnishes and specific UV light sources, which may have higher upfront costs. In the corrugated industry UV inks are mainly used in digital printing based on UV-inks.

When selecting the appropriate drying system, consider factors such as the types of inks and varnishes used, production speed, desired drying/hardening time, available space, budget, and environmental considerations. Consulting with equipment manufacturers, suppliers, and industry experts can provide valuable insights and help determine the most suitable drying system for your specific requirements.

BEST PRACTICES INDEX: CONVERTING

Converting

AUXILIARIES

COMPRESSED AIR SYSTEM

In corrugated board manufacturing, compressed air system is used to power various machines and components that are essential to the manufacturing process. Compressed air is used to operate pneumatic cylinders, valves, and actuators that control the movement of the corrugator and converting machines. A typical schematic layout of compressed air system is presented in Fig. 11.

The compressed air system in a corrugating plant typically consists of the following components:

- Air compressor: The air compressor is the heart of the compressed air system. It compresses atmospheric air and delivers it to air receiver tanks for use in the manufacturing process.
- Air dryer: The air dryer removes moisture from the compressed air to prevent corrosion and damage to the machines and components.
- Air receiver tanks: The air receiver tanks store compressed air for immediate use by the machines and components. They also act as a buffer to prevent rapid cycling of the air compressor.
- Air filters: The air filters remove dust, dirt, and other contaminants from the compressed air to prevent damage to the machines and components.
- Air distribution piping: The air distribution piping distributes compressed air to the machines and components throughout the plant.
- Regulators and controls: The regulators and controls regulate the pressure and flow of the compressed air to ensure consistent operation of the machines and components.

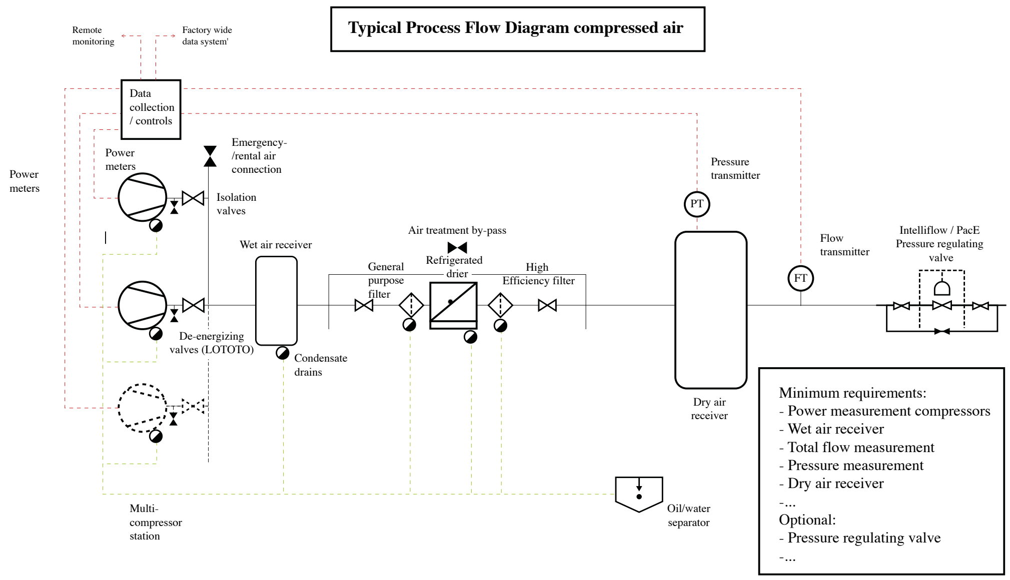


Fig. 11 ***Compressed-air system*** *(Source: Ingersoll Rand)*

Best practice measures related to compressed air system in the context of corrugated board production and conversion are presented in the following text.

Link to EEQ results for compressed air system Fig. S 4 EEQ results - Auxiliaries (compressed air system)

Check the required network pressure of the compressed air and fix it as low as possible

Check the required network pressure of the compressed air in your facility and fix it as low as possible. This approach is identified as a good practice to help minimize energy consumption, reduce unnecessary pressure losses, and promote energy efficiency throughout the compressed air system.

Assess the specific requirements of the machinery and its associated equipment that rely on compressed air. Determine the minimum acceptable pressure needed to maintain efficient and reliable operation. Identify any pressure losses that occur within the compressed air system. Common sources of pressure loss include air leaks, undersized pipes, excessive filtration, and improper system design. Addressing these losses can significantly reduce the required network pressure.

Based on the measured network pressure, the compressed air requirements of the equipment, and the allowable pressure drop, set the network pressure to the lowest possible value that meets the operational needs of the machinery. Consult with equipment manufacturers and industry standards to determine the optimal pressure range for each specific application.

Continuously monitor the network pressure to ensure it remains within the desired range. Adjust as necessary to maintain the lowest possible pressure while still meeting the operational requirements of the machinery. Educate employees and operators about the importance of maintaining lower network pressures and the associated energy-saving benefits. Encourage a culture of energy efficiency and empower staff to identify and report any deviations from optimal pressure settings.

According to the survey the measure has low implementation rate, about 30% with an additional 3% planned.

A technology supplier emphasized this measure as a good practice to minimize electricity consumption. Experts from the industry strongly agree with the technology supplier's assessment on this topic.

Check the siziwwng of the whole compressor system

Perform a comprehensive audit of the existing compressed air system. Identify all the compressed air-consuming equipment, including their air flow and pressure requirements. Assess the efficiency and performance of the current compressor system and associated components.

Based on the compressed air demand assessment and the performance data collected, calculate the required capacity and capabilities of the compressor system. Consider factors such as maximum and average air flow rates, required pressure levels, and any peak demand periods. Consider boosters to amplify pressure at point of application instead of producing all compressed air at maximum pressure.

Use a variable speed drive (VSD) compressor to balance compressor output

Compressed-air production can be precisely matched with the demand using VSD compressor, resulting in better control and energy efficiency.

Assess compressed-air demand and understand the requirements of compressed-air system in your facility. Determine the average and peak demand, as well as any fluctuations in demand over time.

Select and install a VSD compressor suitable for your compressed-air system. Set up the VSD compressor by following manufacturer's guidelines and configure it to match your system needs. This typically involves connecting it to the control system and configuring parameters such as motor speed range, pressure setpoints, and control mechanisms.

Continuously monitor the system's performance and make necessary adjustments to ensure balanced compressed-air production. Perform routine maintenance to keep the compressor in optimal condition, including checking for leaks, cleaning filters, and addressing any issues that may affect production.

According to an interview with a technology supplier, the optimal operational capacity range for a VSD compressor falls between 40% and 70% of its full capacity. It is recommended to use dedicated fixed-speed units instead of having a VSD unit run under 40% or over 70% of its full capacity over extended periods.

Separate the smallest suitable compressor for weekend usage

Review the compressors available in your system and identify the smallest suitable one that can fulfill your weekend compressed air needs. This involves assessing the capacity, output, and suitability of each compressor for the intended applications.

Separate the identified compressor for weekend usage and reduce energy consumption by avoiding running larger compressors on partial load unnecessarily. This allows you to meet the compressed air needs specifically during weekends while efficiently utilizing the compressed air system during other times.

Investigate to replace old compressors by energy efficient ones

Begin by assessing the current compressors and their energy consumption. Conduct an energy audit to determine the energy efficiency and overall performance of the existing compressors. Identify the specific areas where energy savings can be achieved.

Research and identify energy-efficient compressor models suitable for your corrugator plant. Consider factors such as compressor type (e.g., rotary screw, reciprocating), capacity, control features, and energy-saving technologies incorporated into the design. Evaluate the compatibility of the new compressors with the existing infrastructure, such as the electrical supply, air distribution system, and control systems. Ensure the new compressors can seamlessly integrate into the corrugator plant without major modifications.

Using the specifications and energy data of the new compressors, estimate the potential energy savings that can be achieved by replacing the old compressors. Consider factors such as improved efficiency, reduced leakage, and advanced control systems.

Industry experts recommend assessing the financial implications of the compressor replacement project. Consider the upfront costs of the new compressors, potential energy savings, ROI, and any available incentives or rebates for energy-efficient equipment.

Replace old (uncontrolled) refrigeration dryers by energy efficient ones with better control

By replacing old, uncontrolled refrigeration dryers with energy-efficient models that offer better control, you can improve energy efficiency, reduce operating costs, and enhance the overall performance of compressed air system.

Evaluate the performance, energy consumption, and control capabilities of your existing refrigeration dryers. Identify the limitations and areas for improvement. Examine the control features offered by the energy-efficient refrigeration dryers. Consider features like dew point control, integrated sensors for monitoring inlet and outlet conditions, automatic modulation of refrigeration capacity, and communication interfaces for system integration and remote monitoring. Estimate the potential energy savings that can be achieved by replacing the old refrigeration dryers with energy-efficient models. Consider factors such as improved control accuracy, reduced energy consumption during idle periods, and optimized operation based on demand.

Avoid too small pipe cross sections of the compressed air network (flow speeds > 6 m/s)

Proper pipe sizing helps minimize pressure drop, reduce energy consumption, and ensure reliable compressed air supply to support corrugator and converting operations.

Determine the maximum compressed air demand of the corrugated board plant. This includes assessing the required flow rates for various equipment, machinery, and processes that rely on compressed air. Use appropriate engineering calculations or software tools to determine the required pipe sizes based on the compressed air demand and the allowable flow velocity. The goal is to maintain acceptable pressure drop levels, which is directly linked to energy consumption by the compressors.

As a good practice measure to minimize pressure drop and energy loss, it was indicated in the questionnaire that velocity in pipes do not exceed 6 m/s. This was later endorsed by industry experts during the workshop.

Clean the suction filters on a regular basis to minimize the pressure drop

Regularly cleaning the suction filters in the compressed air system helps maintain optimal airflow, minimizes pressure drop, and ensures the efficient operation of downstream equipment.

Determine a regular cleaning schedule based on the operating conditions and the manufacturer's recommendations for the suction filters. Factors such as air quality, dust levels, and usage patterns can influence the frequency of cleaning.

According to the survey results, this measure is a standard practice in the industry with an implementation rate of about 80% and additional 8% planned in the short term.

Demand from the machine manufacturers that they avoid using compressed air when it is not necessary

By actively engaging with machine manufacturers and advocating for reduced compressed air usage, drive positive change and contribute to a more energy-efficient corrugator plant. Collaboration, clear communication, and a focus on long-term sustainability are key to successfully influencing machine manufacturers and promoting energy-efficient solutions.

Gain a thorough understanding of the specific applications and processes for which the machine manufacturers currently utilize compressed air. Identify areas where compressed air is used but can potentially be replaced with alternative technologies or methods. Initiate a dialogue with the machine manufacturers to discuss ideas and express the importance of avoiding unnecessary compressed air usage. Request their commitment to prioritize energy efficiency and explore alternative technologies or methods for specific applications.

According to an interview with a compressed air equipment supplier, they actively provide service and support for replacing unnecessary use of compressed air.

Replace compressed air jets by electric motor blowers

Replacing compressed air jets with electric motor blowers can offer energy savings and operational benefits. Assess the current compressed air usage in the plant. Identify the applications where compressed air jets are being used, such as air knives, air amplifiers, or air blow-offs. Understand the specific requirements of each application, including the required air volume and pressure.

Evaluate electric motor blowers as an alternative to compressed air jets. Electric motor blowers, also known as centrifugal blowers or fans, use electric power to generate airflow. Look for blowers with suitable airflow capacity, pressure capabilities, and efficiency ratings to meet the requirements of your applications.

Use automatized devices to stop the air flow when machines or machine parts are stopped

Using automated devices, such as valves to stop the airflow when machines or machine parts are stopped can help optimize energy consumption and reduce compressed air wastage.

Identify the specific machines or machine parts in the plant that require compressed air during operation. Determine the points where compressed air flow needs to be controlled or stopped when the machines or parts are not in use. Consider installing automatic control systems, this may involve incorporating valves or other similar devices, at the desired locations in the compressed air network. Collaborate with experts in automation and compressed air systems to ensure the successful implementation of this solution.

Experts from the industry emphasized the importance of this measure as a good practice. However, the implementation rate today is rather very low, covering only 9% of the surveyed plants with an additional 17% planning to apply the measure shortly.

Close the air valves entering the machines that are not used, if possible in automatic manner

Closing the air valves entering machines that are not in use helps prevent wasteful air consumption and conserves energy. By implementing automatic valve closure systems, ensure that the valves are closed promptly and reliably, reducing unnecessary air leakage and optimizing energy efficiency.

Identify air valves that supply air to machines or equipment that are not in use during specific periods. This can include idle machines or machines that operate intermittently. Install automatic valve control systems that can detect the operational status of the machines and close the air valves when they are not in use. These systems can be integrated with machine sensors or timers to determine the on/off status of the equipment.

The implementation rate of this measure is rather low covering only 11% of the surveyed plants and an additional 21% indicating plans to act shortly.

Eliminate unnecessary use of compressed air, e.g., blowing and cleaning purposes

By systematically eliminating unnecessary use of compressed air for blowing and cleaning purposes, reduce energy consumption, lower operational costs, and enhance the overall performance of the corrugating process.

Perform a thorough assessment to identify areas where compressed air is being used for blowing and cleaning applications. Explore alternative cleaning methods that are more efficient and use less compressed air. For example, consider using mechanical brushes, or specialized cleaning equipment that operate on electricity.

Raise awareness among employees about the importance of conserving compressed air and the need to minimize its use for blowing and cleaning. Train them on alternative methods and tools that can achieve similar results without relying on compressed air. Foster a culture of energy conservation and responsible compressed air use among employees.

Use the waste heat from the compressors

Consider installing heat recovery systems to capture and utilize the waste heat from the compressors. These systems typically consist of heat exchangers that transfer the heat from the compressor's cooling system to another medium, such as water or air.

Identify suitable heat sinks such as space heating for direct recovery of waste heat towards applications within the corrugated board plant. This can involve heating office spaces, workshops, or other areas where heat is required for maintaining comfortable working conditions.

Utilize the waste heat to preheat water for various purposes, such as process heating, equipment cleaning, or sanitation. By preheating the water, less energy is required to raise its temperature to the desired level, resulting in energy savings.

Redirect the waste heat to assist in drying applications within the plant. For instance, heat can be used to aid in the drying process of corrugated sheets or other materials, reducing the reliance on external heating sources.

According to an interview with a technology supplier, compressor manufacturers provide the option to preorder units with built-in heat exchanger system to facility waste heat recovery. Corresponding to the pressure levels of compressed air in corrugated board industry, preheated fluid return temperature 70–75ºC can be expected.

Perform compressed air audit

By conducting compressed air audit focused on energy savings and implementing the identified opportunities, reduce energy consumption and optimize the efficiency of your compressed air system.

Measure the actual compressed air demand and establish the baseline air consumption and identify areas where demand can be reduced or optimized. Evaluate the performance and efficiency of compressors. Measure their power consumption and compare it to the output of compressed air. Assess the control settings and load/unload cycles of the compressors to ensure they are operating optimally.

LIGHTING AND FACTORY HEATING

This section documents best practices related to lighting system, factory heating and office space heating.

Link to EEQ results for lighting and factory heating Fig. S 5 EEQ results - Auxiliaries (Lighting and factory heating)

Define the required standard for lighting and check it with the existing installation

By defining the required lighting standard and checking it against the existing installation, identify areas that need improvement and take appropriate actions to achieve optimal lighting conditions in your corrugator plant. Determine if there are opportunities to upgrade to more energy-efficient lighting technologies, such as LED lighting, to reduce energy consumption and operating costs.

This measure is standard practice with an implementation rate covering over 80% of the surveyed plants, and an additional 12% planning to do so in the short term.

Use efficient lamps: replace non efficient by efficient (LED) lighting

By replacing non-efficient lighting with energy-efficient LED lighting, reduce energy consumption, lower maintenance costs, and enhance lighting quality in the facility. This measure is standard practice with an implementation rate covering over 85% of the surveyed plants, and an additional 10% planning to act shortly. Moreover, the survey indicated switching to LED lighting achieves as much as 25% energy saving on lighting.

EU REGULATION ABOUT LIGHTING

Install light detectors for places with non-continuous use

Installing light detectors in areas with non-continuous use is a smart approach to optimize energy usage and enhance energy efficiency in your facility. Light detectors, such as occupancy sensors or motion sensors, can automatically control lighting based on occupancy or activity levels.

Identify areas in the plant where lighting is not continuously required, such as storage rooms, restrooms, hallways, or low-traffic areas. These areas are ideal candidates for light detectors. Assess the specific needs of each area and determine the appropriate type of light detector. Occupancy sensors detect human presence, while motion sensors detect movement. Choose the type that aligns with the usage patterns and requirements as well as work safety of each area.

This measure has an implementation rate, covering 60% of the surveyed plants, and an additional 40% planning to act in the short term.

Investigate skylights for natural light at roof repair

By investigating skylights for natural light during roof repair, improve the working environment in the corrugator plant, reduce reliance on artificial lighting, and potentially save energy. Proper planning, selection, and installation are key to achieving the desired benefits of skylights in your facility.

Evaluate the lighting needs of your plant. Identify areas that could benefit from increased natural light, such as production floors, workstations, and storage areas. Consider the desired illumination levels and the specific tasks performed in each area.

Automize opening/closing doors by detecting the forklift movements

Automating the opening and closing of doors by detecting forklift movements can enhance work safety and minimize heat losses. Adjust the opening and closing delay of the doors to minimize the duration that the doors are open, reducing the amount of time heat can escape or cold air can enter the facility.

Educate employees and forklift operators about the importance of minimizing heat losses through doors. Encourage them to close doors promptly after passing through and avoid propping doors open unnecessarily.

Consider the insulation of poorly insulated roofs during renovation projects

By considering the insulation of poorly insulated roofs during renovation projects, exploit the opportunity to improve energy efficiency, reduce heat losses, and create a more comfortable working environment. Proper insulation selection, installation, and ongoing monitoring are key to achieving optimal energy savings.

Evaluate the heat losses of the current roofing system. This includes analyzing heat transfer, conducting thermal imaging inspections, and assessing energy consumption patterns to determine the potential benefits of improving roof insulation.

Determine the required insulation level based on local building codes, energy efficiency standards, and best practices. Consult with insulation experts or energy consultants who can help calculate the appropriate thermal resistance values and recommend suitable insulation materials for your specific roof type.

Avoid factory heating directly from steam boiler

For a corrugated board plant running the corrugator three shifts and minimum six days, factory heating with heat from the steam boiler and a steam/ hot water heat exchanger is the easiest and very efficient way.

For plants in one or two shift mode running not the whole week, the capacity of the steam boiler can be to too large for heating when the corrugator is stopped. This leads to low efficiency of the boiler. In this case, a separate hot water boiler for factory heating and the possibility of utilizing waste heat from existing processes should be evaluated.

Assess the integration requirements of the chosen alternative heating technology with your factory's existing infrastructure. This may involve modifications to ductwork, control systems, or other components to ensure seamless integration and optimal performance.

Conduct a financial analysis that compares the upfront costs, operating costs, and potential energy savings associated with alternative heating technologies. Consider factors such as payback period, ROI, and long-term cost savings to determine the economic viability of the proposed solutions.

Control and regulate the heating/ cooling temperatures where possible on daily/ hourly basis

Controlling and regulating the heating and cooling temperatures on a daily or hourly basis in the office spaces can help optimize energy usage and create a comfortable working environment.

Assess existing heating, ventilation, and air conditioning (HVAC) system to understand its capabilities, controls, and zones. Identify areas where temperature control is necessary or can be improved. Determine the desired temperature ranges for different areas of your plant based on comfort requirements, process needs, and energy efficiency considerations. Consider factors such as occupancy levels, machinery heat generation, and specific environmental conditions.

Consider installing programmable thermostats or building automation systems that allow scheduling temperature adjustments throughout the day. These devices can automatically raise or lower temperatures based on preset time schedules, optimizing energy usage during occupied and unoccupied periods.

DRIVES, BELTS AND MISCELLANEOUS UNITS

The section covers various components and systems related to drives and belt systems, power transmission and miscellaneous equipment required for the operation of typical corrugated board production and conversion plant.

Link to EEQ results for miscellaneous units Fig. S 6 EEQ results - Auxiliaries (others)

Use flat belt drive instead of V-belts to reduce friction and minimize electricity consumption

Using flat belt drives instead of V-belts can help reduce friction and minimize electricity consumption in the corrugator drive systems.

Evaluate the current V-belt drives in your plant and identify areas where flat belt drives can be implemented. Consider factors such as the power requirements, load characteristics, and operating conditions of the equipment. Determine the appropriate specifications for the flat belts based on the power transmission requirements.

Continuously evaluate the performance of the flat belt drives and seek opportunities for further improvement. Consider implementing energy-efficient technologies, such as variable frequency drives (VFDs) or motor upgrades, to optimize power transmission and reduce energy consumption further.

Go for highest available efficiency class when investing on new electric motor drives

The energy efficiency of an electric motor is calculated as the ratio of the mechanical output power to the electrical input power. The energy efficiency level is expressed in International Energy efficiency classes (IE), IE1 being the lower class and IE5 the highest. Under the current EU regulation, motors must reach the IE2, IE3 or IE4 efficiency level depending on their rated power and other characteristics. For instance, three-phase motors with a rated output between 0.75kW and equal to or below 1000kW must reach the IE3 level by July 2021. Motors between 75kW and 200kW must meet the IE4 level as of July 2023 (EU REGULATION 2019/1781, 2019). The EU is the first place worldwide making the IE4 level mandatory for some categories of motors.

By investing in the highest available efficiency class of electric motor drives, reduce energy consumption, lower operating costs, and contribute to a more sustainable and energy-efficient plant.

Consult with reputable motor manufacturers or suppliers to understand the range of motor drives available in the market and their respective efficiency ratings. Inquire about the highest available efficiency class and its compatibility with your intended applications.

In applications where motor speed control is necessary, consider investing in variable speed drives (VSDs) or variable frequency drives (VFDs). These drives allow you to match motor speed to the load requirements, thereby improving energy efficiency by avoiding unnecessary energy consumption.

Consider the total cost of ownership, including the initial purchase cost and the long-term energy savings, when selecting motor drives. Although higher efficiency motors may have a higher upfront cost, the energy savings over the motor's lifespan can often offset the initial investment.

Replace DC motors by AC motors

By replacing DC motors with AC motors, you can benefit from improved energy efficiency, simplified control systems, and reduced maintenance requirements. Proper selection, installation, and monitoring will ensure a successful transition to AC motors in the plant.

Assess whether AC motors can effectively replace DC motors in your applications. Consider the load characteristics and the ability of AC motors to provide the required torque and speed control. Choose the appropriate type of AC motor based on your specific application requirements. Common AC motor types include induction motors, synchronous motors, and permanent magnet motors. Select the motor type that best matches your torque and speed control needs. Compare the energy efficiency of the AC motors with the existing DC motors. Look for high-efficiency AC motors that meet or exceed the efficiency levels of the DC motors. Consider the potential energy savings over the motor's lifespan. Moreover, if applications require variable speed control, incorporate VFDs along with the AC motors. VFDs allow precise speed control and energy optimization by adjusting the frequency and voltage supplied to the motor.

Check the condition of the transformers

Well-maintained transformers operate more efficiently, resulting in reduced energy losses and improved overall energy performance. Additionally, monitoring energy consumption and tracking performance metrics can help identify opportunities for further energy savings and continuous improvement.

Review the loading patterns of the transformers to ensure they are operating within their optimal range. Transformers operate most efficiently when loaded between 30% and 70% of their rated capacity. If transformers are consistently overloaded or underutilized, it can lead to energy inefficiencies. Adjust load distribution or consider resizing transformers if necessary.

This measure is rather a standard practice, covering nearly 80% of the surveyed plants and an additional 10% planning to act shortly. Moreover, the surveyed indicated that transformers are routinely checked as part of regular maintenance in most surveyed plants.

Check the power factor correction

By checking and improving the power factor correction, reduce reactive power consumption, improve energy efficiency, and potentially lower electricity costs.

Understand and monitor power factor. Power factor is a measure of how effectively electrical power is being used at a plant. It represents the ratio between real power (measured in kilowatts, kW) and apparent power (measured in kilovolt-amps, kVA). A power factor of 1 indicates efficient power usage, while a power factor less than 1 indicates reactive power consumption. Fig. 12 shows how much system apparent power (kVA) can be released by improving power factor. In practice, power factor correction to 95% provides maximum benefit (Eaton, 2022).

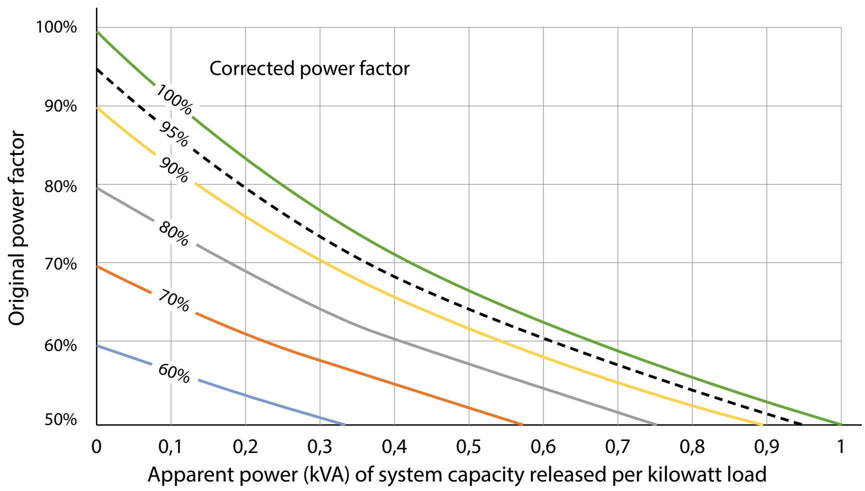


Fig. 12 Corrected power factor releases system apparent power (kVA)

Conduct a power factor analysis and identify areas with low power factor and high reactive power consumption. Apply appropriate corrective measures to improve power factor. Common methods of power factor correction include:

- Capacitor banks: Install capacitor banks to offset reactive power consumption and improve power factor. Capacitors provide reactive power locally, reducing the burden on the electrical distribution system.
- Power factor correction equipment: Depending on the size and complexity of your plant, you may consider installing power factor correction equipment such as static VAR (Volt-Amperes-Reactive) compensators (SVCs) or active power factor correction devices. These devices dynamically adjust reactive power to maintain a high-power factor.
- Load balancing: Uneven distribution of electrical loads can contribute to a poor power factor. Evaluate the balance of loads across phases and redistribute loads as necessary to improve power factor.

Power factor correction is rather a common practice, covering nearly 70% of the plants surveyed. Experts from the industry have also stressed the importance of power factor correction during the workshop.

Install temperature sensors to stop airco below certain temperature at airconditioned electrical rooms and cabinets

By installing temperature sensors and implementing temperature-based controls, regulate the operation of air conditioning units in your air-conditioned electrical rooms and cabinets more efficiently. This approach helps prevent excessive cooling and reduces energy consumption, leading to cost savings and improved sustainability.

Identify optimal locations to place the temperature sensors. Position them in areas where they can accurately measure the ambient temperature and reflect the conditions inside the electrical rooms and cabinets. Consider avoiding direct exposure to airflow or heat sources that could affect the sensor readings. Connect the temperature sensors to the control system responsible for operating the air conditioning units.

Go for flocculation instead of electrolysis at the water treatment

Choosing flocculation instead of electrolysis for water treatment can indeed help save energy. Flocculation generally requires less energy compared to electrolysis, making it an energy-efficient option.

Flocculation relies on chemical additives to facilitate the clumping of particles in water, which generally requires less energy compared to the electrical energy needed for electrolysis. Electrolysis involves the use of electric current to induce chemical reactions, which consumes more energy.

Flocculation is effective for removing suspended solids, organic matter, and other contaminants present in water. If your water treatment needs primarily involve particle removal and clarification rather than specific ion removal or disinfection, flocculation is a more energy-efficient option.

While flocculation offers energy-saving benefits, it's essential to consider the specific water treatment requirements of your corrugator plant. Factors such as the nature of contaminants, water quality standards, and regulatory compliance should be evaluated to determine the most appropriate water treatment method.

It is advisable to consult with water treatment experts or specialists who can assess your plant's specific needs and recommend the most energy-efficient solution for your water treatment process. They can provide insights into the design, implementation, and operation of a flocculation system to optimize energy savings while ensuring effective water treatment.

Flocculation is a widespread practice in the corrugated board industry with an implementation rate covering 65% of the plants surveyed.

ADDITIONAL PRACTICES RELATED TO AUXILIARIES

Additional measures discussed but deemed as standard practice or not mature today are presented below.

Conduct air balancing checks on a regular basis

Air balancing in the context of HVAC (Heating, Ventilation and Air Conditioning) refers to the complex process of ensuring that air is distributed evenly and efficiently throughout a building or space. Properly balanced air systems help maintain a comfortable and controlled environment while reducing energy waste.

Common air balancing issues can be detected by controlling temperature, pressure, airflows and air filters. Air filters should be cleaned on regular basis to avoid airflow restriction. In addition, maintaining correct pressure differentials between inside and outside is essential for proper performance. A slight overpressure is needed to avoid unwanted airflow from outside.

Investigate replacing poor insulated windows/ doors

Determine the required insulation levels for windows and doors based on local building codes, energy efficiency standards, and best practices. Consider factors such as thermal transmittance values, solar heat gain coefficient, and air infiltration rates.

Evaluate the condition and performance of existing windows and doors. Look for signs of air leakage, deteriorating seals, or inadequate insulation. Consider factors such as frame material, glazing type, and overall efficiency ratings. Plan the replacement project in a way that minimizes disruption to your operations. Coordinate with contractors to schedule the installation during periods of reduced activity or planned downtime.

Check if the daylight gates in the roof are properly closed when the plant is heated

Establish a routine and a checklist for proper plant operation and instruct operators to strictly follow them. Familiarize employees with how the daylight gates operate. They may be manual or automated, depending on the design and installation. Ensure employees understand the controls or mechanisms involved in opening and closing the gates.

BEST PRACTICES INDEX: AUXILIARIES

MONITORING AND ORGANISATION

Picture VDW

This chapter summarizes topics common to all plant sections and/or topics of organisational nature. Some of these topics are also addressed in the ISO 50001 Energy Management (ISO 50001, 2018), which is already implemented in many plants.

Link to EEQ results for monitoring and organisational topics Fig. S 7 EEQ results - Monitoring and organisation

Avoid energy consumption outside production hours by regular checks if all consumers are switched off

By implementing regular checks to ensure all consumers are switched off outside production hours, avoid unnecessary energy consumption and lower energy costs in your corrugator plant. Consistent monitoring, automation, employee engagement, and ongoing improvements can help optimize energy efficiency and promote sustainable practices.

Conduct an energy consumption audit to identify all energy-consuming equipment and areas in a corrugated board production and conversion plants. This will help create a comprehensive list of consumers that need to be checked. Designate specific individuals or a team responsible for conducting regular checks during non-production hours. Clearly communicate their roles and responsibilities, emphasizing the importance of energy conservation and the need to switch off all consumers when not in use. In addition, consider installing automated controls, such as timers, motion sensors, or occupancy sensors, to automatically switch off lights and other equipment when not in use. This can help reduce reliance on manual checks and provide additional energy-saving benefits.

Determine the frequency and timing of the checks. Consider conducting checks at the end of each shift or before the start of the next working day. Adjust the schedule based on your plant's operating hours and energy consumption patterns.

Monitor energy consumption data and compare it against expected consumption levels during non-production hours. Analyze any discrepancies or unexpected energy usage to identify areas that may require additional attention or improvements.

Experts from industry and technology suppliers have highlighted the relevance of this measure as a good practice. Technology suppliers suggested that the KPIs to be communicated with them when the industry aims to achieve energy saving targets that involve the help of technology manufacturers. According to the survey, the implementation rate is low, reaching 50% with the remaining 50% planning to act in the short term.

Measure the baseload of electricity, steam and compressed air to identify energy losses

Regular measurement and analysis of baseload consumption for electricity, steam, and compressed air can help identify energy losses and target areas for improvement. By implementing energy-saving measures based on the findings, optimize energy efficiency, reduce energy waste, and achieve cost savings in your corrugated board plant.

Data analysis and identification of energy losses:

- Analyze consumption patterns: Review the collected energy consumption data for electricity, steam, and compressed air. Identify the baseload, which represents the minimum energy consumption during non-production or idle periods.
- Compare with expected baseload: Compare the measured baseload with the expected or ideal baseload. Significant deviations may indicate energy losses or inefficiencies.
- Identify energy losses: Investigate areas where energy losses are evident. This can include leaks in compressed air systems, inefficient equipment operation, steam leaks, or excessive standby power consumption.
- Conduct energy audits: Perform detailed energy audits to assess specific areas with high energy losses. Engage energy experts or consultants to conduct comprehensive assessments and recommend energy-saving measures.

Implement energy-saving measures:

- Address identified losses: Take appropriate actions to address the identified energy losses. This can include repairing leaks, optimizing equipment operation, improving insulation, upgrading inefficient systems, or implementing control measures.
- Monitor and track improvements: Continuously monitor energy consumption after implementing energy-saving measures to evaluate their effectiveness. Compare the post-improvement data with the baseline to quantify energy savings achieved.

Experts from the industry stressed the importance of this measure during the workshop. The survey showed low implementation covering less than 20% of the surveyed plants and an additional 65% planning to act in the short term.

Measure the energy consumption in detail and report key metrics on a regular basis

By measuring energy consumption in detail and reporting key metrics on a regular basis, proactively monitor energy performance, identify areas for improvement, and drive energy efficiency initiatives in your corrugator plant. Regular reporting and communication of energy metrics will help raise awareness, engage stakeholders, and foster a culture of energy efficiency throughout the organization.

Identify and define key energy metrics for regular monitoring.

- Determine key energy metrics that are most relevant for your corrugator plant. Common metrics include total energy consumption (electricity, steam, and compressed air), specific energy consumption (per unit of production), energy intensity (energy per unit area or product), and peak demand.
- Establish energy targets and benchmarks based on industry standards, best practices, or previous performance. These targets will serve as reference points for evaluating energy performance and progress over time.

Report and communicate key energy metrics.

- Prepare periodic reports summarizing the key energy metrics, trends, and performance against targets. Include visual representations such as charts or graphs to enhance understanding and facilitate comparisons.
- Share the energy reports with relevant stakeholders, including management, production teams, and energy champions. Ensure that the reports are easily accessible and clearly communicate the energy performance of the corrugated board plant.
- Schedule regular energy review meetings to discuss the reports, highlight achievements, address concerns, and identify opportunities for further energy optimization. Encourage open discussions and solicit feedback and suggestions from participants.

Experts from the industry identified this measure as a good practice and recommended it for implementation across the corrugated board sector. The survey showed about 50% of the plants surveyed implement certain levels of energy monitoring, with an additional 30% planning to act in the short term.

Carryout energy audits and use them as a tool to assist in energy reduction

Carrying out energy audits can be a valuable step towards identifying energy inefficiencies and implementing measures for energy reduction. An energy audit is a systematic assessment of energy consumption and usage patterns within a facility or process.

Conduct a comprehensive site survey to identify energy-consuming equipment, assess their condition, and identify potential energy wastage. This may include checking for leaks, inefficient equipment, and areas with unnecessary energy usage. Analyze the collected data to understand the patterns of energy usage, peak consumption periods, and areas with high energy intensity.

Based on the audit findings, identify potential energy conservation opportunities. These may include upgrading equipment to more energy-efficient models, improving insulation, optimizing processes, and implementing energy-saving practices.

Periodically repeat the energy audit to track progress and identify new opportunities for energy reduction. Energy management should be an ongoing process to ensure continuous improvement.

Expertise from the industry have recognized this measure as a good practice and recommended for its implementation. The survey showed nearly 45% of the sampled plants have this measure implemented while an additional 30% have indicated plans to do so shortly.

Use automated energy monitoring/ targeting systems

Automated energy monitoring and targeting systems provide real-time visibility into energy consumption and facilitate data-driven decision-making. By implementing such systems in your corrugator plant, manage energy usage more effectively, identify areas for improvement, and drive continuous energy efficiency enhancements.

Explore the market for energy monitoring and targeting systems that are suitable for industrial applications. Consider factors such as functionality, compatibility with existing infrastructure, ease of use, and scalability. Look for features such as real-time data monitoring, automated data collection, energy analytics, reporting capabilities, and integration with energy meters and other equipment. Consult with industry experts, attend trade shows, and seek recommendations from other companies in your sector to gather insights and feedback on different energy monitoring and targeting systems.

Establish energy reduction targets or efficiency goals based on industry standards, best practices, or your organization's objectives. These targets can be specific to certain processes, areas, or time periods. Set up alarms and notifications within the energy monitoring and targeting system to alert responsible personnel when energy consumption exceeds predetermined thresholds, indicating potential energy waste or inefficiencies.

Utilize the automated energy monitoring system to track energy consumption trends, compare actual performance with targets, and identify deviations or areas requiring further attention. Regularly report on energy performance improvements, energy savings, and cost reductions achieved through the implementation of energy-saving measures. Share these achievements with relevant stakeholders to promote awareness and engagement.

Expertise from the industry agreed on the relevance of this measure as a good practice. According to the survey, its implementation is rather low covering only 15% of the surveyed plants with an additional 60% planning to act shortly.

Discuss key metrics with the operational teams and consider their feedback

Engaging with the operational teams and incorporating their feedback is crucial for the successful implementation of energy management initiatives. By discussing key metrics with the operational teams, gain valuable insights, foster collaboration, and ensure the effectiveness of your energy-saving efforts.

Communicate the purpose and importance of KPIs. Explain to the operational teams why energy management is essential for the corrugator plant. Emphasize the potential cost savings, environmental benefits, and the role each team member plays in achieving energy efficiency goals. Discuss how energy consumption and efficiency directly affect production processes, machine performance, and overall operational efficiency. Illustrate how energy-saving initiatives can lead to process improvements and cost reductions.

Discuss any challenges or barriers the operational teams may face in implementing energy-saving measures. Address their concerns and seek solutions collaboratively. Encourage the operational teams to contribute innovative ideas for energy efficiency improvements. Foster a culture of continuous improvement by recognizing and implementing valuable suggestions.

Evaluate the feedback and ideas received from the operational teams. Prioritize the ones that align with energy management goals and have the potential for significant impact. Implement the feedback-driven improvements in collaboration with the operational teams. Provide necessary resources, support, and training to ensure successful implementation. Share the outcomes and results of the implemented improvements with the operational teams. Celebrate successes, recognize contributions, and communicate the positive impact achieved through their involvement.

The survey showed about 43% of the sampled plants hold certain form of discussion focused on KPIs with operational teams on a regular basis, e.g., monthly, while an additional 23% have indicated plans to implement in the short term.

Conduct benchmarks with other plants on a regular basis

By conducting benchmarks with other plants, gain insights into industry best practices, identify areas for improvement, and drive continuous energy performance improvement. The collaborative nature of benchmarking encourages knowledge sharing, fosters healthy competition, and facilitates the adoption of energy-saving initiatives.

Identify benchmarking partners. Look for industry associations or networks that facilitate benchmarking initiatives among corrugator plants or similar manufacturing facilities. These organizations can connect you with other plants willing to participate in benchmarking activities. Reach out to other corrugator plants directly and propose collaborative benchmarking efforts. Sharing knowledge and experiences with similar facilities can be mutually beneficial.

Define benchmarking metrics. Identify KPIs that are commonly used in the industry. This may include metrics such as energy consumption per unit of production, specific energy consumption, or energy intensity. Consider other metrics related to operational efficiency, waste reduction, or sustainability to gain a comprehensive understanding of performance areas that extend beyond energy usage.

Gather energy consumption data from your corrugated board plant, including electricity, steam, compressed air, and any other significant energy sources. Ensure data accuracy and consistency by using standardized measurement methods. Establish a secure data exchange mechanism with benchmarking partners to share aggregated, anonymized data. This protects confidential information while enabling meaningful comparisons.

Collaborate with benchmarking partners to exchange insights, challenges, and successful practices. Conduct regular meetings, workshops, or virtual conferences to facilitate knowledge sharing.

Expertise from the industry strongly agree on the relevance of this measure as a good practice. The survey showed about two-third of the plants responded implement this measure and an additional 27% have indicated plans to act in the short term.

Use an energy reduction plan with appropriate targets

By setting targets for energy reduction, regularly reviewing and updating the plans, establish a roadmap for achieving energy efficiency goals. Monitoring progress, engaging employees, and fostering a culture of energy conservation will contribute to sustained energy reduction and long-term cost savings.

Establish realistic targets. Determine the level of energy reduction you aim to achieve within a specific timeframe. Ensure that the targets are ambitious yet attainable. Consider industry benchmarks, regulatory requirements, and your plant's current energy performance.

Break down targets into tasks. Divide the overall energy reduction target into smaller, actionable tasks. These can be based on specific processes, equipment, or areas of the plant. Assign responsibilities for each task to relevant individuals or teams.

Evaluate the achieved energy savings, cost savings, and overall performance against the targets set. Identify areas of improvement and learn from both successes and failures. Set new energy reduction targets for subsequent periods based on the learnings and achievements of the previous phases. Gradually raise the bar to continuously drive energy efficiency improvements.

According to the survey, 50% of the plants implement certain forms of energy reduction targets and an additional 27% indicated plans to act shortly.

Use a preventive maintenance plan with updates on a regular basis

Implementing a preventive maintenance plan with regular updates is not only crucial for equipment reliability but also for reducing energy consumption. By integrating energy-saving practices into preventive maintenance plans, identify and address energy inefficiencies in equipment and systems, resulting in reduced energy consumption and cost savings. Regular updates and continuous improvement will ensure that maintenance activities align with energy-saving objectives and optimize the overall energy performance of the corrugator plant.

During routine equipment inspections, incorporate specific energy-related checks to identify any issues affecting energy efficiency. This may include lubricating bearings, inspecting insulation, seals, air leaks, and cooling systems.

Monitor and measure equipment performance regularly to identify deviations from optimal energy consumption. Use energy meters, sensors, or data loggers to track energy usage patterns and identify potential energy-saving opportunities.

This measure has rather low implementation rate covering nearly 30% of the sampled plants with an additional 4% indicating plans to act shortly.

Clearly define the responsibility for improvements, actions and corrective measures

By clearly defining responsibilities and fostering a culture of accountability, ensure that energy management efforts are effectively implemented, monitored, and continuously improved. This will drive energy efficiency, cost savings, and a sustainable approach to operations.

Establish a dedicated team or designate specific individuals responsible for overseeing energy management efforts. The team should include representatives from various departments, such as operations, maintenance, engineering, and management.

Clearly outline the improvement targets and actions required to achieve energy efficiency goals. Assign responsibility to the appropriate team or individual for each specific improvement target or action item. This could include tasks such as equipment upgrades, process optimization, training programs, or policy changes.

Implement a reporting and feedback system to track progress and ensure effective communication within the organization. Regularly review and update key performance indicators (KPIs) related to energy consumption, energy savings, and other relevant metrics. Set up reporting mechanisms to capture data, share updates, and document achievements.

Interviews with equipment and material suppliers highlighted the relevance of this measure as a good practice. The survey also showed nearly 50% of the sampled plants have this measure implemented with an additional 26% indicating plans to do so in the short term.

Train teams and individuals to operate equipment according to best practice

Training teams and individuals to operate equipment according to best practices is essential for optimizing efficiency and minimizing energy waste.

Assess the specific training needs of your teams and individuals. Consider the type of equipment they operate, their roles and responsibilities, and any areas of improvement identified through audits or performance evaluations.

Design comprehensive training programs that cover both theoretical knowledge and practical skills. Tailor the training content to the specific equipment and processes used in at a corrugating facility. Topics may include equipment operation, maintenance, energy-saving techniques, safety protocols, and troubleshooting.

Collaborate with equipment manufacturers to provide specialized training on their specific equipment.

They can share insights on efficient operation, maintenance practices, and any unique features that can enhance energy efficiency.

Emphasize the importance of following established best practices for equipment operation. This includes setting proper operating parameters, ensuring regular maintenance, avoiding unnecessary idling, and minimizing energy-consuming activities during non-production periods.

Encourage ongoing learning and improvement by organizing refresher training sessions, workshops, and knowledge-sharing forums. Foster a culture of continuous improvement where teams and individuals are encouraged to contribute their ideas and experiences to enhance energy efficiency.

Evaluate the effectiveness of training programs through assessments, feedback surveys, or performance metrics. Use this feedback to improve training content and delivery methods for future sessions.

Interviews with equipment and material suppliers identified this measure as a good practice. Moreover, nearly 46% of the survey respondents implement this measure while an additional 26% have indicated plans to act shortly.

Train teams and individuals in energy management

Training teams and individuals in energy management can help create a culture of energy efficiency and sustainability within your facility.

Start by creating awareness among your teams about the importance of energy management and its impact on the environment, cost savings, and overall sustainability. Share relevant information and statistics to highlight the benefits of energy conservation.

Offer basic energy management training to provide teams and individuals with a foundational understanding of energy efficiency concepts, best practices, and techniques. This training can cover topics such as energy auditing, energy-saving opportunities, energy monitoring and targeting, and behavior change for energy conservation. Tailor the training programs to the specific roles and responsibilities of different teams and individuals within your corrugator plant. For example, provide targeted training for equipment operators, maintenance personnel, supervisors, and managers, focusing on energy-saving practices relevant to their respective areas.

Invite energy management experts or consultants to conduct specialized training sessions. These professionals can provide in-depth knowledge, practical tips, and guidance on energy management strategies specific to the corrugator industry.

Emphasize the role of individual behavior in energy conservation. Train teams and individuals on energy-saving habits such as turning off lights and equipment when not in use, adjusting temperature settings, and adopting efficient work practices. Encourage them to become energy champions and lead by example.

Equip teams and individuals with the necessary tools and resources to support energy management efforts. This may include energy monitoring and tracking software, energy-saving guidelines and checklists, and access to relevant documentation and reference materials.

The survey showed nearly 40% of the respondents have this measure implemented while an additional 35% have indicated plans to act shortly.

BEST PRACTICES INDEX: MONITORING & ORGANISATION

REFERENCES

- Bosch. (2023). *Bosch planning tool for steam boiler systems*. https://www.boiler-planning.com/efficiency/basics/combustion-efficiency.html
- Chow, S., Ganji, A. R., San Francisco, P., & Hackett, B. (2005). Opportunities for energy efficiency and demand response in corrugated cardboard manufacturing facilities. *IETC - Industrial Energy Technology Conference*. https://hdl.handle.net/1969.1/5585
- Daniela, R., Holger, J., & Johannes, K. (2012). *Industry Energy Concept for Corrugated Board - Measures to Increase Energy Efficiency in the Production of Corrugated Board*.
- DETR. (1996). *The UK corrugated packaging industry*.
- Eaton. (2022). *Power factor correction: A guide for the plant engineer*. https://www.eaton.com/content/dam/eaton/products/low-voltage-power-distribution-controls-systems/power-factor-corrections/portfolio/eaton-pfc-guide-plant-engineer-SA02607001E.pdf
- FEFCO. (2023). *Climate Neutrality Roadmap 2050: For the Corrugated Cardboard Industry*. https://www.fefco.org/sites/default/files/documents/FEFCO_RoadmapResults_overview2023.pdf
- ISO 50001. (2018). *ISO 50001 Energy management systems* (Issue 2). https://www.iso.org/iso-50001-energy-management.html#:~:text=ISO%2050001%20is%20based%20on,improve%20quality%20and%20environmental%20management
- Parr, S. (2021). *Energy Efficiency Framework - an approach to develop best practice in corrugated sector of the print and paper industry* [PhD Thesis]. University of Derby.
- EU REGULATION 2019/1781, L272/83 (2019). https://eur-lex.europa.eu/eli/reg/2019/1781/oj

ANNEX 1: RECOMMENDED BEST PRACTICES INDEX

STEAM GENERATION AND DISTRIBUTION

CORRUGATING

CONVERTING

Topics

AUXILIARIES (COMPRESSED AIR SYSTEM)

AUXILIARIES (LIGHTING AND FACTORY HEATING)

AUXILIARIES (OTHERS)

MONITORING AND ORGANISATION

ANNEX 2: SUMMARY OF EEQ RESULTS AND INTERVIEWS

The EEQ contained a total of 93 topics classified into five process areas:

- steam generation (19)
- corrugating (16)
- converting (10)
- auxiliaries (36, compressed-air system 15, lighting and factory heating 10, belt and drive systems 11)
- monitoring and organisation (12)

The total number of topics increased to 121 following the interviews with equipment suppliers and industry experts. The additional topics are listed at the end of each category.

The EEQ responses covered a total of 115 plants across Europe of which integrated 99, sheet feeders 5 and converting 11. This corresponds to about 17% of the total number of corrugated board and conversion plants in Europe. The corresponding production amounted to 8.73 billion square meters, about 16% of total production in Europe.

While the survey covers a subset of the total plants in Europe, analysing the data from the 115 plants can still provide valuable insights on energy performance and potential improvements. By leveraging the findings and extrapolating the results to the broader population, it is possible to make informed recommendations and encourage energy-saving initiatives in the corrugated board production and conversion industry.

The total number of best practice topics raised in the survey including those derived from the interviews may not necessarily correspond to best practice topics indexed in this handbook. Topics deemed standard practice or those corresponding to long-term perspective are excluded from the best practice measures addressed by this book.

STEAM GENERATION

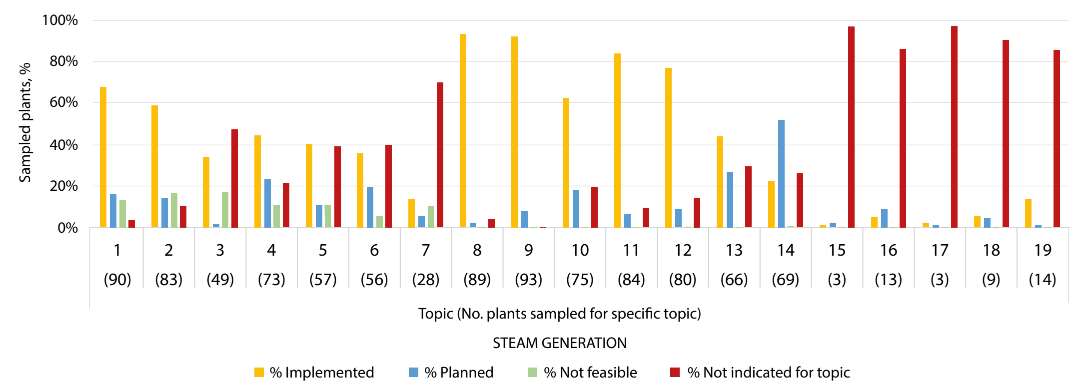


Fig. S 1 EEQ results – Steam Generation

Topics

Reduce exhaust gas heat losses by oxygen and/ or CO burner control or by measuring oxygen/ CO on regular basis	1
Use a variable drive for the blower of the boiler	2
Use reverse osmosis for desalination	3
Use automatic conductivity control: install automatic sluice on the boiler instead of manual sluice	4
Use automated desalination regulator controlled through the conductivity of boiler water	5
Use an economiser for the preheating of the feed water	6
Use a heat exchanger after the economiser for hall heating or fresh-water heating or heating of the boiler inlet air	7
Insulate the whole steam and condensate system	8
Perform regular checks on insulation, steam leaks, condensate traps and implement corrective actions immediate after	9
Perform audits of the steam and condensate system on a regular basis	10
Use a closed loop steam and condensate system	11
Using a closed loop steam and condensate system: maximize closed loop, recover condensate in a high-pressure tank	12
Use a cascade system for steam utilization in series	13
Monitor the percentage of the fresh water relative to the steam production or condensate return	14
Decarbonisation: install an electric boiler	15
Decarbonisation: install a solid biomass boiler	16
Decarbonisation: use biomethane as replacement for natural gas	17
Decarbonisation: install a CHP (combined heat and power) system	18
Decarbonisation: use a heat pump system for the heating of the buildings	19
Additional topics	
Ensure to have "dry steam" (slightly superheated steam) before the corrugator	
Exhaust gas condenser	
Monitor inefficient or damaged insulation	
Synchronize the operation time of the corrugator and the boiler house	
Link the controls of the boiler house and the steam system	
For longer than 90 mins standby install automatic control on steam to hotplates, single facer & double backer	

CORRUGATING

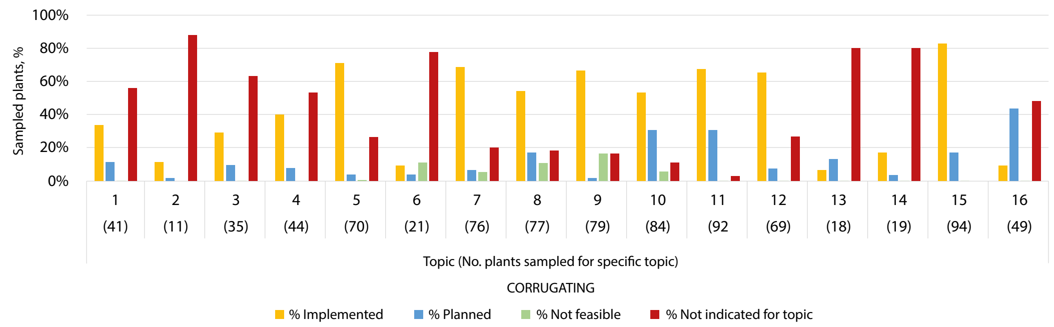


Fig. S 2 EEQ results - Corrugating

Topics

Replace pressure membrane glue pumps by electrical membrane pumps or peristaltic pumps	1
Buffer the water after it passes through the glue tanks and use it as hot mixing water afterwards	2
Take measures to increase adhesive dry substance, e.g. investigate the option to use “glue boosters” or rheology modifiers	3
Minimize glue use by investigating glue gap system and control	4
Investigate glue application roll specs to reduce glue use	5
Use rest heat to increase the temperature of paper reel storage (reduces the fresh steam consumption at the corrugator)	6
Reduce starting/ shutdown processes or downtimes and increase the output per hour at the corrugator	7
Install temperature sensors at the exit of the preheaters and use a closed loop wrap arms control system	8
Run as cool as possible on the corrugator (may need significant investment)	9
Use a process control system at the corrugator	10
Use peripherical heated corrugating rolls and hot plates	11
Reduce steam pressure on the preheaters to a maximum 9 - 10 bars	12
Study the influence of the belt of the doublebacker on steam and electricity consumption	13
Study the influence of the loading system on the heating plates on steam and electricity consumption	14
Measure and report the specific steam consumption of the corrugator on a regular basis	15
Evaluate heat recovery from the cabinets of the single facers	16

Additional topics	
Reduce waste	
Clean the glue rolls on a regular basis	
Enable zero wrap (especially for lightweight papers)	
Run the settings of the glue gap in automatic mode for precise glue application	
Use stored data to compare the energy consumption of similar orders and rectify deviations immediately	
Wish to FEFCO: define standard grades to enable a comparison of machinery/ technical solutions from the suppliers	
Clean the hot plates of the doublebacker on a regular basis	
Ensure correct web tension for optimum heat transfer	
Reduce/ optimize the use of spray steam	
Integrate the spray steam supply into the Single Facer	
Measure specific glue consumption in real time	
Reduce steam pressure while stand-by operation	
Use control valves for the separate heating cylinders of the preheater	
Use a double facer steam supply with automatic switch between live and spray steam	
Consider the different bonding properties of paper from different suppliers	

CONVERTING

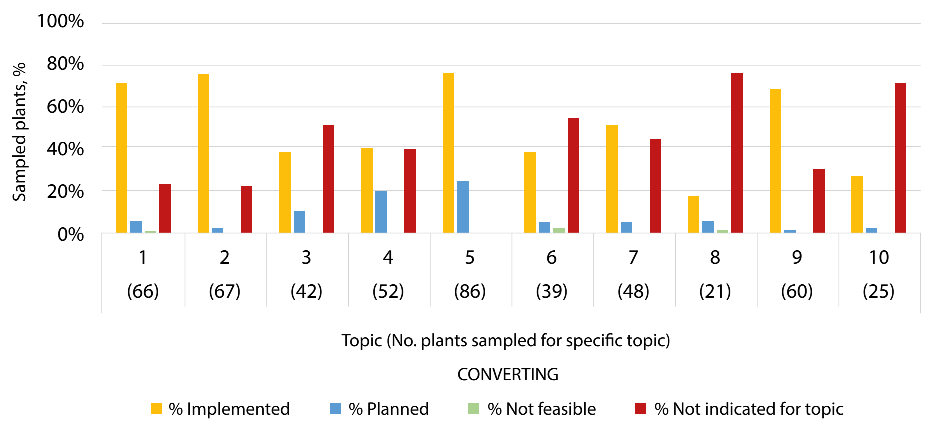


Fig. S 3 EEQ results - Converting

Topics

Check the settings of the IR dryers in printing machines. Use them only for orders where there are really required	1
Prefer IR dryers where the external modules are switched on according to the working width	2
Replace pressure membrane ink pumps by electrical membrane pumps or peristaltic pumps	3
Replace hydraulic units by electric driven units	4
Using hydraulic units: turn them off outside production time	5
Recuperate the air of vacuum/ air transport systems after filtering	6
Use a belt system for the transport of the cutting waste instead of a vacuum system with ventilators	7
Using a vacuum system with ventilators: investigate the possibility to shut down ventilators at idling of the machine(s)	8
Reduce the no-load rate on the shredder and baler	9
Choose the appropriate source of drying system for drying of inks and hardening of varnish	10

AUXILIARIES 1 (COMPRESSED-AIR SYSTEM)

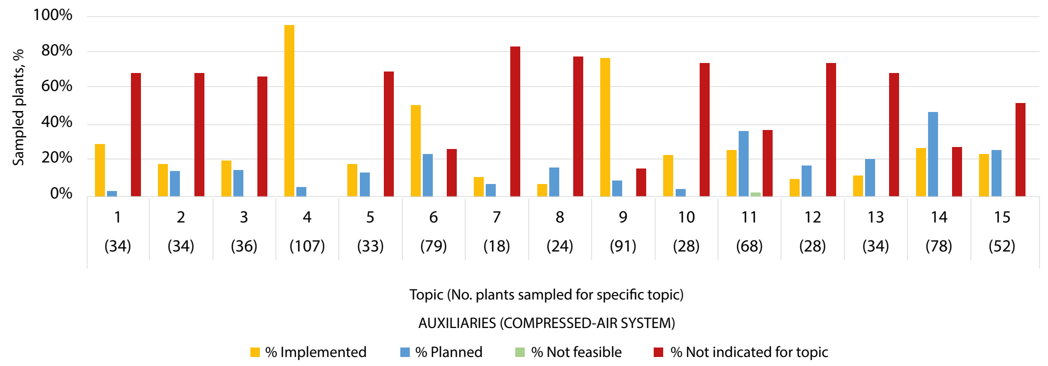


Fig. S 4 EEQ results - Auxiliaries (compressed air system)

Topics

Check the required network pressure of the compressed air and fix it as low as possible	1
Monitor and control pressure level delta between pressure on compressor and pressure on network	2
Check the sizing of the whole compressor system	3
Use a frequency driven compressor to balance compressor output	4
Separate the smallest compressor for weekend usage	5
Investigate to replace old compressors by energy efficient ones	6
Replace old (uncontrolled) refrigeration dryers by energy efficient ones with better control	7
Avoid too small pipe cross sections of the compressed air network (flow speeds > 6 m/s)	8
Clean the suction filters on a regular basis to minimize the pressure drop	9
Demand from the machine manufacturers that they avoid using compressed air when it is not necessary	10
Replace compressed air jets by electric motor blowers	11
Use automatized devices to stop the air flow when machines or machine parts are stopped	12
Close the air valves entering the machines that are not used, if possible, in automatic manner	13
Eliminate unnecessary use of compressed air, e.g., blowing and cleaning purposes	14
Use the waste heat from the compressors	15
Additional topics	
Identify and study pressure levels at application points for compressed air	
Leasing of compressors	
Air receiver size and location; place near the highest-pressure point of application/s to minimize losses	
Compressed air audit	

AUXILIARIES 2 (LIGHTING AND FACTORY HEATING)

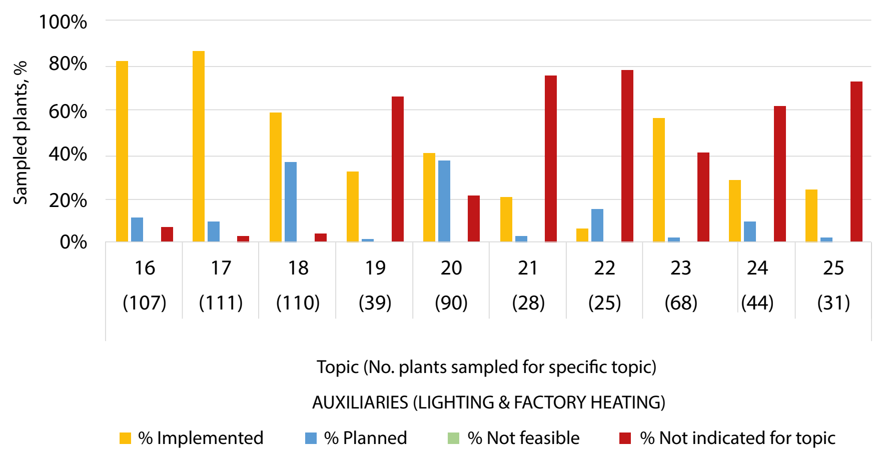


Fig. S 5 EEQ results - Auxiliaries
(Lighting and factory heating)

Topics

Define the required standard for lighting and check it with the existing installation	16
Use efficient lamps: replace non efficient (Neon) by efficient (LED) lighting	17
Install light detectors for places with non-continuous use	18
Investigate skylights for natural light at roof repair	19
Automize opening/closing doors by detecting the forklift movements	20
Consider the insulation of poorly insulated roofs while having projects (roof repair, ...)	21
Investigate replacing poor insulated windows/ doors	22
Check if the daylight gates in the roof are properly closed when the plant is heated	23
Avoid factory heating directly from steam boiler. Investigate installing aerotherms on gas, use rest steam or other rest energy	24
Control and regulate the heating/ cooling temperatures where possible on daily/ hourly basis	25

AUXILIARIES 3 (OTHERS)

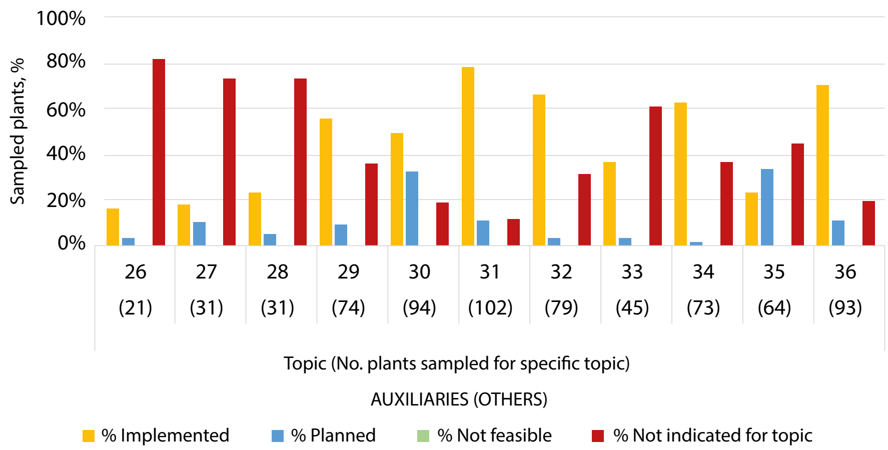


Fig. S 6 EEQ results - Auxiliaries (others)

Topics

Use flat belt drive instead of V-belts to reduce friction and minimize electricity consumption	26
Go at renewal or investment of electric motors for the highest available efficiency class	27
Replace DC motors by AC motors	28
Use variable-frequency drives (AC drives) according to the actual power requirement	29
Measure and report the specific electricity consumption on a regular basis and as detailed as possible	30
Check the condition of the transformers	31
Check the power factor correction	32
Install temperature sensors to stop airco below certain temperature at airconditioned electrical rooms and cabinets	33
Go for flocculation instead of electrolysis at the water treatment	34
Decarbonisation: renewable electricity sources, e.g., install PV (solar panels), wind turbine	35
Decarbonisation: use of electric forklifts wherever possible	36

MONITORING AND ORGANISATION

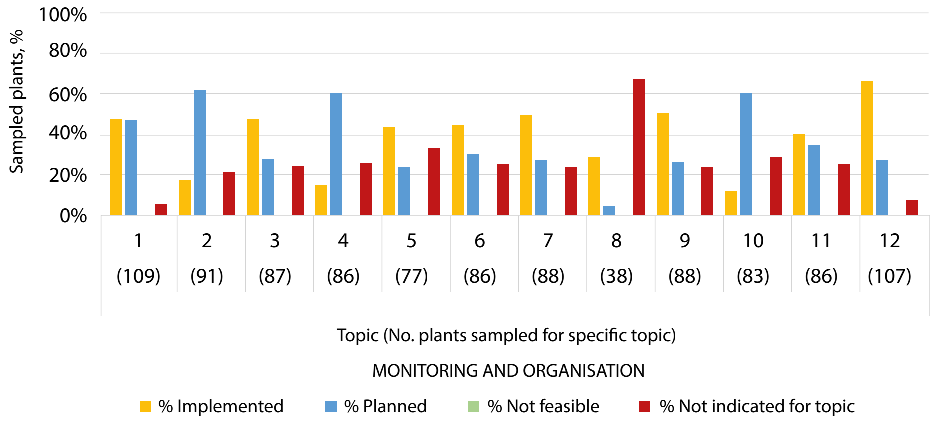


Fig. S 7 EEQ results - Monitoring and organisation

Topics

Avoid energy consumption outside production hours by regular checks if all consumers are switched off	1
Measure the baseload of electricity, steam and compressed air to identify energy losses	2
Measure the energy consumption in detail and report key metrics on a regular basis	3
Use automated energy monitoring/ targeting systems	4
Discuss key metrics with the operational teams and consider their feedback	5
Carry out energy audits and use them as a tool to assist in energy reduction	6
Use an energy reduction plan with appropriate targets	7
Use a preventive maintenance plan with updates on a regular basis	8
Clearly define the responsibility for improvements, actions and corrective measures	9
Train teams and individuals to operate equipment according to best practice	10
Train teams and individuals in energy management	11
Conduct benchmarks with other plants on a regular basis ***Additional topics*** Mobilise sustainability group at site level Analyze energy-related data by dedicated staff/ as a dedicated task as an input for continuous improvement of the processes	12

RISE Research Institutes of Sweden AB
Box 857, 501 15 Borås, Sweden
Telephone: +46 10-516 50 00
E-mail: info@ri.se
www.ri.se

250 avenue Louise 1050 Brussels
Tel: +32 2 646 4070
E-mail: info@fefco.org
X: @FEFCO
www.fefco.org
FEFCO Instagram: circular_corrugated_cardboard