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Study of the Factors Influencing Calorific Consumption of a Vertical Roller Mill and Solution Proposals to Reduce it at a Cement Factory

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ABSTRACT This paper focuses on the of factors influencing calorific consumption of a vertical roller mill (VRM) and solution proposals to reduce it at a cement factory called X cement factory (for confidentiality reasons). The research aims to identify the main operational, mechanical, and material factors contributing to elevated specific calorific consumption (SCC) and to propose corrective measures for improving energy performance. Data covering a five-month production period are collected from the company's production reports and analyzes using key performance indicators such as feed rate, moisture content, stoppage frequency, and fuel consumption. Results reveal that increased raw material moisture, frequent operational stoppages, and unstable feed rates are the dominant factors leading to higher SCC. The study concludes by proposing technical and organizational measures such as feed rate stabilization, moisture control, preventive maintenance, and improved combustion management. Implementing these measures can significantly reduce calorific consumption, enhance energy efficiency, and promote sustainable cement production.

KEYWORDS
Cement factory
Calorific consumption
Vertical roller mill
Hot gas generator
Process amelioration
Energy efficiency

INTRODUCTION

Energy is one of the basic primary requirements for the existence and growth of any industrial sector (Arto *et al.* 2016; Hammond 2007; Stern 2011). Generally, industrial energy consumption directly affects a country's economic growth (Abbasi *et al.* 2021; Zheng and Walsh 2019; Kümmel 1982). The cement industry is one of the energy-intensive industries which utilizes a sizeable amount of energy (Madlool *et al.* 2013; Sahoo and Kumar 2022). This sector consumes 54% of the World's total delivered energy which is very high compared to other industries (Khan and McNally 2023). In the cement industry, the total energy consumption accounts for 50-60% of the overall manufacturing cost, while thermal energy accounts for 20–25%. At X cement factory thermal energy is mainly required in the drying of the raw material during milling by a VRM (Altun *et al.* 2017a,b). The main processes that occur at X cement factory are mostly grinding, drying, separation and homogenization of raw material (clinker, pozzolana and gypsum) and milling.

Clinker and gypsum are imported from abroad, while Pozzolana is obtained from quarries located within the Cameroonian territory (Achaw and Danso-Boateng 2021; Nkouathio *et al.* 2021; Bayiha *et al.* 2018). However, the locally sourced pozzolana is generally wet and could impact negatively on the production process and quality of the finished product (McCarthy and Dyer 2019; Mohammed 2017; Hossain *et al.* 2021). The VRM is associated with a hot gas generator that produces hot gas used for drying raw materials during milling. Nevertheless, X cement factory has experienced over the years, challenges in the consumption of thermal energy in the milling unit. This is observed by a continuous increase in the calorific consumption of the vertical roller mill which is one of the

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plant's key performance indicators. This has led to instability in the production process and an increase in cost of production.

Over the past years, X cement factory has recorded increasing and fluctuating calorific consumption in the VRM unit, despite relatively stable production rates. This trend implies that more natural gas is being consumed per ton of cement produced. The excessive energy use not only raises production costs but also increases the company's carbon footprint (Bocken and Allwood 2012; Fang *et al.* 2011; Hoffman 2007). A detailed analysis of production data reveals that several factors may contribute to this situation, including fluctuations in feed rate, high moisture content of raw materials, frequent stoppages, and suboptimal combustion conditions in the hot gas generator (HGG). However, the relative impact of each of these parameters on calorific performance remains unclear.

The central problem of this research therefore lies in determining the key operational and process parameters responsible for the increase in calorific consumption and proposing effective measures to ameliorate it. This challenge defines the core problematic of this study: How can the calorific consumption of the VRM at X cement factory be optimized to achieve better energy efficiency and reduced fuel costs? The present study carried out at X cement factory aims to analyze the factors influencing calorific consumption and possible causes of this increase in calorific consumption at the milling unit, then responds by proposing solutions that can reduce it at this unit. The main purpose of this paper is to study the factors influencing the calorific consumption of the vertical roller mill and propose solutions to reduce it, thereby reducing fuel consumption, enhancing drying efficiency and maintaining desired cement quality while keeping cost of production fairly low. The specific objectives are:

- Collect and analyze operational data related to production, gas consumption, and process parameters.
- Determine correlations between SCC and key process variables such as feed rate, moisture content, and stoppages.
- Propose actionable technical and managerial solutions for improving the energy performance of the VRM.

This research is of both technical and economic significance.

- From a technical standpoint, it contributes to improving the understanding of the parameters that govern energy efficiency in cement grinding systems. It provides a methodological framework for diagnosing and optimizing calorific performance using quantitative and quality control tools.
- Economically, the study assists X cement factory in identifying areas where fuel consumption can be minimized, leading to significant cost savings and increased production efficiency. Environmentally, the reduction of energy consumption directly contributes to lowering CO_2 emissions, thereby aligning with the company's sustainability goals and Cameroon's national energy transition strategy.
- Academically, the research serves as a reference for future studies on energy optimization in cement production and related process industries.

This paper is organized into two sections, preceded by an introduction section: Material and methods: and Results. This paper concludes with a conclusion section summarizing the major findings and suggesting future directions for research and industrial improvement.

MATERIALS AND METHODS

The materials are used to carry out this paper: Pen, pencil, note book, personal protective equipment (overall, safety boots and gloves), phone, laptop, Microsoft word and Microsoft Excel. Data collection consists of the procedures of acquisition of data needed for this paper. Data required mainly involves gathering both operational and technical information necessary for analyzing the calorific consumption of the VRM system. This was done at the level of the Production department from the cement plant's control room records, daily and monthly production report sheets, and field observations. This procedure consisted of extracting the various key performance indicators that helped in establishing the correlations between the specific calorific consumption and factors that can influence the calorific consumption, presenting these relationships on graphs and tables, and finally drawing insightful conclusions which will later be used to really pinpoint areas of fault and propose actionable solutions. The data extracted from the daily production reports include:

- Mill running hours and stoppage durations.
- Gas Consumption in m^3.
- Cement production of 3X cement (42.5R) and Falcon (32.5R) cement grades in MT.
- Raw material consumption (clinker, gypsum and pozzolana) in MT.
- Mill feed rate in Tons per hour (TPH).

A sample of a daily production report sheet from which the main data needed was extracted is shown on Figure 1.

In Figure 1, it was as well necessary to gather numerical data from the company's production department from which the data needed to carry out a quantitative analysis of the trends in SCC as well as finding correlations between key performance indicators such as Feed Rate, Total production and grade of the cement produced, mill running hours and raw material consumption with SCC. The data collected is for a period of five months from the month of April 1st to August 31st 2025, showing details of production of 32.5R cement grade and 42.5R cement grade commonly called Falcon and 3X respectively with natural gas as fuel. The key calculations are: Average SCC and average feed rate.

- Average SCC: From the daily production reports, the specific gas consumptions (SGC) in m^3/MT for the production of both 3X cement and Falcon were extracted and the SCC for each month were evaluated in kJ/MT. This then allowed the calculation of the SCC and average specific calorific consumptions (Avg. SCC) for each cement grade for each month using the formulae:

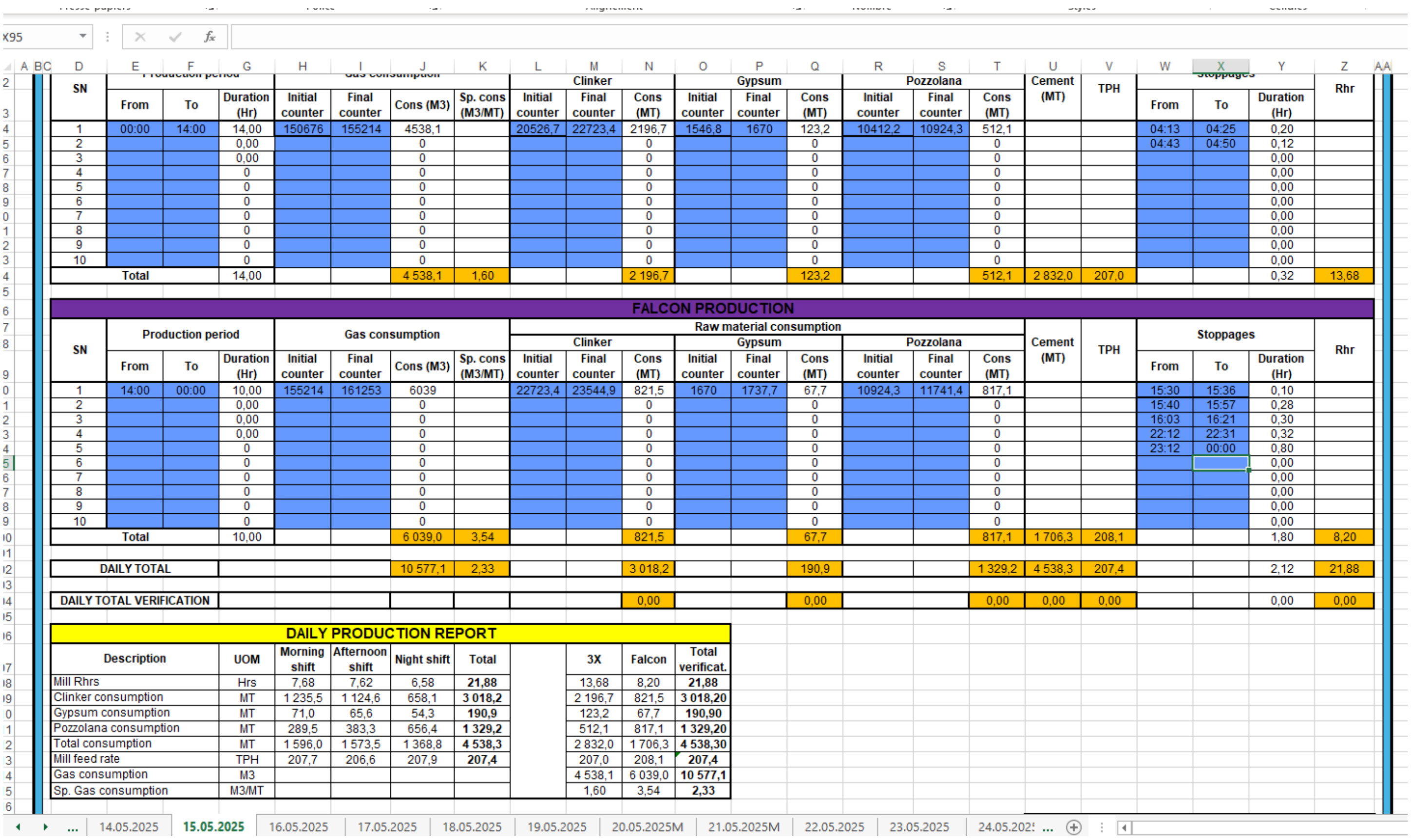
$$\text{SCC} = \text{SGC} \cdot \text{LHV} \cdot \rho_G \tag{1}$$

where SCC = specific calorific consumption in kJ/MT, SGC = specific gas consumption m^3/MT, LHV = Lower heating value of natural gas (50000kJ/kg) and ρ_G = Density of Natural gas (0.712 kg/m^3 according to (Gaz du cameroun, 2016)

$$\text{Avg.SCC} = \frac{\sum \text{SCC}}{\text{Days of consumption}} \tag{2}$$

- Average feed rate: The feed rate was evaluated for each day of the months from the daily production report sheets using the total material consumed (Qm) divided by the actual running hours a day (Rhr). The average value was then calculated for each month in TPH.

$$\text{Feed rate} = \frac{Q_m}{Rhr} \tag{3}$$



SN	Production period From	To	Duration (Hr)	Gas consumption Initial counter	Final counter	Cons (M3)	Sp. cons (M3/MT)	Clinker Initial counter	Final counter	Cons (MT)	Gypsum Initial counter	Final counter	Cons (MT)	Pozzolana Initial counter	Final counter	Cons (MT)	Cement (MT)	TPH	Stoppages From	To	Duration (Hr)	Rhr
1	00:00	14:00	14,00	150676	155214	4538,1		20526,7	22723,4	2196,7	1546,8	1670	123,2	10412,2	10924,3	512,1			04:13	04:25	0,20	
2			0,00			0				0			0			0			04:43	04:50	0,12	
3			0,00			0				0			0			0					0,00	
4			0			0				0			0			0					0,00	
5			0			0				0			0			0					0,00	
6			0			0				0			0			0					0,00	
7			0			0				0			0			0					0,00	
8			0			0				0			0			0					0,00	
9			0			0				0			0			0					0,00	
10			0			0				0			0			0					0,00	
Total			14,00			4 538,1	1,60			2 196,7			123,2			512,1	2 832,0	207,0			0,32	13,68

FALCON PRODUCTION

SN	Production period From	To	Duration (Hr)	Gas consumption Initial counter	Final counter	Cons (M3)	Sp. cons (M3/MT)	Raw material consumption: Clinker Initial counter	Final counter	Cons (MT)	Gypsum Initial counter	Final counter	Cons (MT)	Pozzolana Initial counter	Final counter	Cons (MT)	Cement (MT)	TPH	Stoppages From	To	Duration (Hr)	Rhr
1	14:00	00:00	10,00	155214	161253	6039		22723,4	23544,9	821,5	1670	1737,7	67,7	10924,3	11741,4	817,1			15:30	15:36	0,10	
2			0,00			0				0			0			0			15:40	15:57	0,28	
3			0,00			0				0			0			0			16:03	16:21	0,30	
4			0,00			0				0			0			0			22:12	22:31	0,32	
5			0			0				0			0			0			23:12	00:00	0,80	
6			0			0				0			0			0					0,00	
7			0			0				0			0			0					0,00	
8			0			0				0			0			0					0,00	
9			0			0				0			0			0					0,00	
10			0			0				0			0			0					0,00	
Total			10,00			6 039,0	3,54			821,5			67,7			817,1	1 706,3	208,1			1,80	8,20
DAILY TOTAL						10 577,1	2,33			3 018,2			190,9			1 329,2	4 538,3	207,4			2,12	21,88
DAILY TOTAL VERIFICATION										0,00			0,00			0,00	0,00	0,00			0,00	0,00

DAILY PRODUCTION REPORT

Description	UOM	Morning shift	Afternoon shift	Night shift	Total		3X	Falcon	Total verificat.
Mill Rhrs	Hrs	7,68	7,62	6,58	**21,88**		13,68	8,20	**21,88**
Clinker consumption	MT	1 235,5	1 124,6	658,1	**3 018,2**		2 196,7	821,5	**3 018,20**
Gypsum consumption	MT	71,0	65,6	54,3	**190,9**		123,2	67,7	**190,90**
Pozzolana consumption	MT	289,5	383,3	656,4	**1 329,2**		512,1	817,1	**1 329,20**
Total consumption	MT	1 596,0	1 573,5	1 368,8	**4 538,3**		2 832,0	1 706,3	**4 538,30**
Mill feed rate	TPH	207,7	206,6	207,9	**207,4**		207,0	208,1	**207,4**
Gas consumption	M3						4 538,1	6 039,0	**10 577,1**
Sp. Gas consumption	M3/MT						1,60	3,54	**2,33**

Figure 1 Image of a daily production report sheet from the production department of X cement factory

where Qm = Material Consumed in MT and Rhr = Running hours in Hours

$$\text{Avg.Feed rate} = \frac{\text{Feed rate}}{\text{Days of consumption}} \tag{4}$$

For a proper analysis and understanding of the factors that come into play concerning the high calorific consumption of the VRM and at the level of the HGG, it is necessary for certain relationships between some parameters of production and SCC to be understood in order to be able to draw insightful conclusions that will aid in proposing actionable solutions towards ameliorating the calorific consumption of this unit. The key correlations are:

- Feed rate versus specific calorific consumption.
- Moisture content versus SCC.
- Stoppages versus SCC.

The monthly fuel cost per ton was determined using the relation:

$$\text{Cost} = \text{SGC (m}^3\text{/MT)} \times \text{Price (FCFA/m}^3\text{)} \times \text{production (MT)} \tag{5}$$

where the price at which X cement factory purchases gas is 330.9 FCFA per m^3 (1 MMBTU = 16 USD and 1 MMBTU = 27.3192 m^3. Hence 27.3192 m^3 = 9040FCFA implies 1m^3 = 330.9 FCFA).

RESULTS

This section presents and discusses the results obtained from the analysis of specific calorific consumption trends at X cement factory. It examines the correlations between SCC and operational parameters such as feed rate, moisture content, and stoppages, providing insights into how each factor impacts energy efficiency.

Results of analysis of SCC

To evaluate the energy performance of the VRM, an analysis of the variation in specific calorific consumption was conducted over a five-month period, from April to August 2025. The study utilized daily production data and the corresponding specific gas consumption values obtained from plant operation records. These daily gas consumption data were first converted into their equivalent specific calorific consumption values (in kJ/MT of cement) using the known calorific value of the fuel gas. Table 1 presents the total specific gas consumptions (in m^3/MT of cement) for the various days in the months of April 2025 to August 2025 when the gas generator used Natural gas as fuel.

For each month, the average specific gas consumption and specific calorific consumption are calculated to determine the monthly energy performance trend. Table 2 shows the average values of the SGC and corresponding average SCC.

These monthly averages were then plotted against time to visualize the evolution of energy use during the study period. The resulting graphs reveal a general upward trend in specific calorific consumption from April 2025 to August 2025, indicating a gradual deterioration in the thermal efficiency of the grinding process. Figures 2 and 3 show the graphs of average SGC and SCC , respectively with time.

This increase suggests that the system required progressively more energy to produce fairly the same quantity of finished product (about 4500 MT daily set point) over time. Such a pattern may be attributed to several operational and process-related factors, including variations in feed moisture content, raw material grindability, equipment wearing, suboptimal process control, or

■ **Table 1** Total SCC (in m^3/MT of cement) from April 2025 to August 2025

APRIL 2025	MAY 2025	JUNE 2025	JULY 2025	AUGUST 2025
2.79	1.91	2.05	3.44	3.32
1.64	2.72	4.33	3.39	4.11
2.27	1.98	1.85	2.54	3.49
2.35	2.75	2.66	2.91	/
2.84	2.79	2.22	3.40	/
2.06	2.72	2.74	4.80	/
2.74	2.91	2.67	4.29	/
/	2.95	3.31	2.30	/
/	2.59	2.82	2.60	/
/	3.60	2.37	1.60	/
/	5.09	2.50	2.17	/
/	2.32	/	2.75	/
/	2.79	/	2.29	/
/	2.59	/	0.26	/
/	2.33	/	/	/
/	0.88	/	/	/
/	0.01	/	/	/

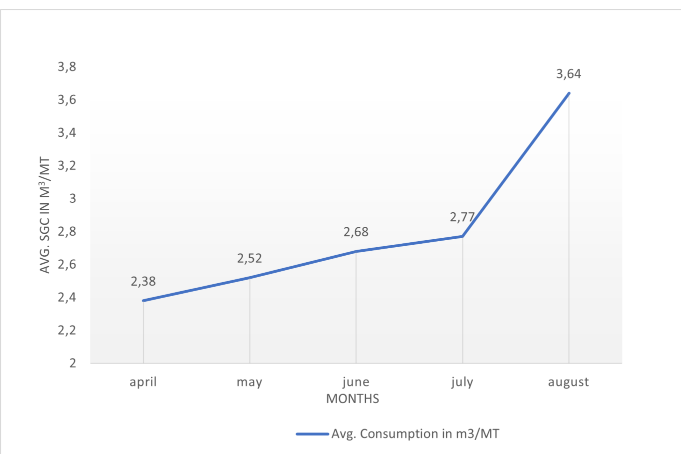


Figure 2 Graph of Avg. SGC with time.

frequent stoppages affecting thermal stability. The observed trend emphasizes the need for continuous monitoring and optimization of operating parameters to maintain stable and efficient VRM performance.

To quantify the economic impact of the variations in energy performance observed during the study period, a cost analysis was conducted based on the monthly SGC values. The month of April was used as the baseline because it recorded the lowest specific

■ **Table 2** Average values of SGC and SCC

Months	Average SGC (m^3/MT)	Average SCC (kJ/MT)
APRIL 2025	2.38	84728
MAY 2025	2.52	89712
JUNE 2025	2.68	95408
JULY 2025	2.77	98612
AUGUST 2025	3.64	129584

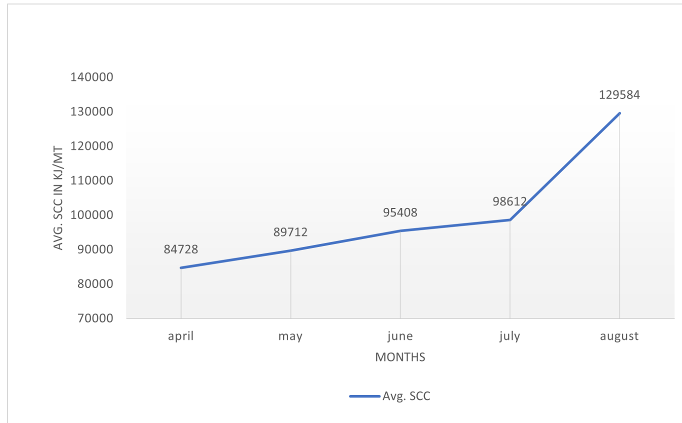


Figure 3 Graph of Avg. SCC with time.

gas consumption (2.38 m^3/MT). All subsequent months were compared to April to estimate the additional fuel cost incurred due to higher consumption rates. Table 3 shows the values of the cost of the different quantities of natural gas used up during the studied months.

■ **Table 3** Monthly cost of fuel consumed

MONTH	AVG. SGC (m^3/MT)	PRODUCTION (MT)	TOTAL COST (FCFA)
APRIL 2025	2.38	4682	3687271.644
MAY 2025	2.52	4791	3995061.588
JUNE 2025	2.68	3867	3429302.004
JULY 2025	2.77	3932	3604043.676
AUGUST 2025	3.64	4603	5544203.028

The analysis of the SGC and its associated costs over the months from April to August reveals a clear trend in energy usage and expenditure for the production process. In April 2025, the average SGC was 2.38 m^3/t, corresponding to a production volume of 4,682 tons and a total gas cost of 3,687,271.644 FCFA. This month serves as the baseline for comparative analysis. In May 2025, the average SGC slightly increased to 2.52 m^3/t while production rose to 4,791 tons, resulting in a total cost of 3,995,061.588 FCFA. This indicates that despite higher production, the increase in gas consumption per ton contributed to a proportional rise in total fuel cost. For June 2025, the average SGC further increased to 2.68 m^3/t; however, production decreased to 3,867 tons. Consequently, the total gas cost was 3,429,302.004 FCFA. Although the production was lower, the increase in SGC demonstrates a reduction in energy efficiency, suggesting that the process consumed more gas per ton of product. In July 2025, the average SGC continued to rise to 2.77 m^3/t with a production of 3,932 tons, leading to a total cost of 3,604,043.676 FCFA. The trend indicates a steady increase in specific gas consumption over time, which negatively impacts operational efficiency even when production volumes remain relatively stable. A significant increase is observed in August 2025, where the average SGC reached 3.64 m^3/t, with production at 4,603 tons. This resulted in a total cost of 5,544,203.028 FCFA, representing the highest gas expenditure within the analyzed period. The sharp rise in SGC reflects an intensified loss in energy efficiency, highlighting the need for corrective measures to optimize fuel consumption and reduce operational costs.

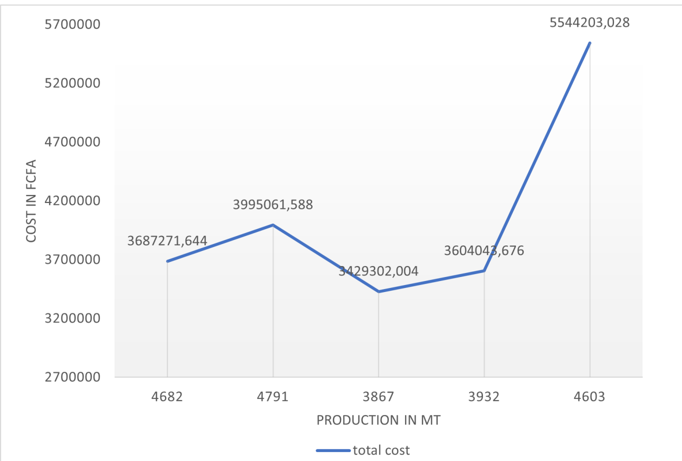


Figure 4 Graph of cost versus production.

Overall, these results of Figure 4 clearly show that higher SGC values directly translate into increased production costs with an extra difference of 1856931.384 FCFA when comparing April's 2025 fuel cost and that of August 2025. Thus, emphasizing the importance of monitoring and controlling specific gas consumption to ensure energy-efficient operation.

Results of feed rate versus SGC and SCC

To further understand the energy performance of the VRM, the relationship between the average feed rate and the specific energy consumption indicators namely; the SGC and the SCC is analyzed. Table 4 shows a record of daily feed rate values for each month extracted from the daily production reports from the production department.

The monthly average feed rate, calculated from daily production data, is plotted against the corresponding average SGC and SCC values for the period from April 2025 to August 2025. Table 5 shows the average feed rates of each month with the corresponding values of SGC and SCC.

Figures 5 and 6 show the graphs of average feed rates in TPH plotted against average SGC and average SCC, respectively.

The resulting trend shows an inverse correlation between the feed rate and both SGC and SCC. During months when the feed rate was relatively high (such as April with 208.9 TPH), the SGC and SCC values were comparatively low (2.38 m^3/MT and 84,728 kJ/MT, respectively). Conversely, as the feed rate decreased between May and June, the energy consumption values increased noticeably. This relationship indicates that a lower feed rate tends

Table 4 Daily feed rates for each month

APRIL 2025	MAY 2025	JUNE 2025	JULY 2025	AUGUST 2025
211.6	218.7	173.8	201.0	194.1
206.2	208.9	196.3	199.9	197.5
209.5	215.4	188.9	209.6	188.8
211.3	206.8	191.3	198.8	192.9
208.9	209.7	189.0	183.1	/
208.0	208.8	184.4	176.5	/
206.8	190.7	189.0	196.3	/
/	180.6	188.3	199.8	/
/	212.6	192.7	205.9	/
/	207.4	208.3	191.6	/
/	183.9	207.7	200.3	/
/	199.5	205.7	193.5	/
/	204.0	/	/	/
/	197.5	/	/	/
/	175.5	/	/	/
/	173.1	/	/	/
/	200.0	/	/	/
/	188.0	/	/	/
/	196.0	/	/	/
/	192.0	/	/	/

to reduce the mill's energy efficiency, as more fuel energy is required to maintain the necessary drying and grinding conditions for smaller throughputs. However, very high values of feed rates will lead to poor quality finished products.

The observed trend can be attributed to the operational principle of the VRM, where stable material flow and optimal bed thickness are essential for efficient grinding and heat transfer. At lower feed rates, the system experiences higher heat losses and reduced utilization of hot gases, leading to higher specific calorific consumption. Therefore, maintaining an optimal feed rate (between 200–215 TPH) is crucial to achieving lower energy consumption and improved thermal performance of the system. This correlation confirms that feed rate is a significant operational parameter influencing the thermal efficiency of the VRM and should be continuously monitored and controlled as part of the energy optimization strategy.

Results of the correlation between moisture content and SCC

The influence of raw material moisture on energy performance was also analysed by comparing the SGC and SCC for the two cement grades produced at X cement factory namely 3X cement (42.5R) and Falcon (32.5R). Although both products are derived from the same raw materials, their compositions differ mainly in

Table 5 Average feed rate values for each month

MONTHS	AVERAGE FEED RATE (TPH)	AVG. SGC (m^3/MT)	AVG. SCC (kJ/MT)
APRIL 2025	208.9	2.38	84728
MAY 2025	187.0	2.52	89712
JUNE 2025	191.0	2.68	95408
JULY 2025	193.0	2.77	98612
AUGUST 2025	195.3	3.64	129584

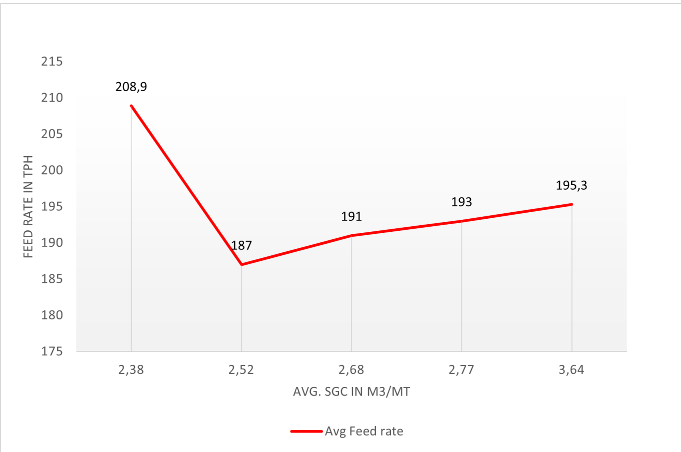


Figure 5 Graph of Average feed rate against AVG. SGC.

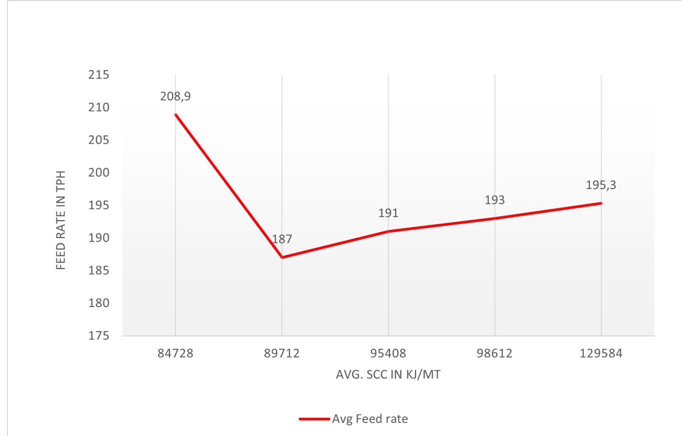


Figure 6 Graph of Average feed rate against AVG. SCC.

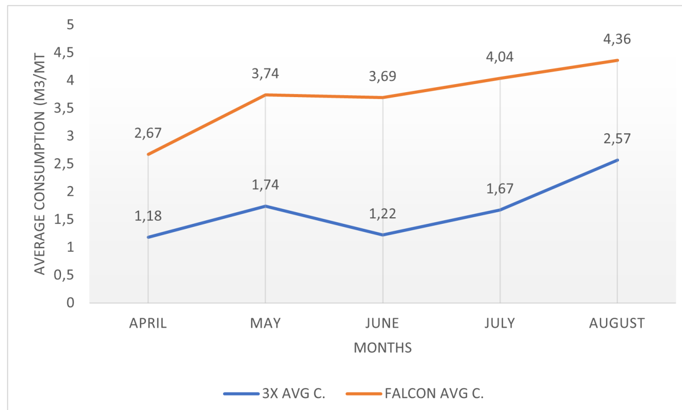


Figure 7 Graph of average SGC of 3X versus falcon.

the proportion of pozzolana. The Falcon grade typically contains a higher percentage of pozzolana (ranging between 35% and 55%) while the percentage in 3X cement is relatively lower (21–35%), which is generally wet when coming from the quarry, particularly during the rainy season. Table 6 presents the average values of SGC and SCC of 3X cement and Falcon and their corresponding average production.

The comparative analysis of the average SGC and SCC values for the two cement grades shows that, for nearly equivalent levels of production, the Falcon cement consistently exhibits higher energy consumption than the 3X cement. This difference can be attributed primarily to the higher moisture content of the raw materials used in Falcon production since more pozzolana which contributes more to the moisture content of the raw material is more in Falcon than in 3X cement. Increased moisture requires additional thermal energy to achieve effective drying within the VRM, thereby increasing both the gas demand and the specific calorific consumption of the process. Figures 7 and 8 are graphs that show how the average values of SGV and SCC for Falcon are generally always higher than that of 3X cement.

The results clearly demonstrate that raw material moisture content is directly proportional to specific energy consumption. A rise in moisture necessitates more heat input for drying, which elevates the SCC and consequently reduces the overall thermal efficiency of the system. This finding highlights the importance of raw material pre-drying or moisture control strategies, especially during the rainy season, to optimize fuel usage and minimize calorific losses during grinding operations.

Results of the correlation between stoppages and SCC

Another important parameter investigated in this study is the effect of operational stoppages on energy performance, particularly their relationship with the SGC and SCC. Using the daily production reports from April to August, the number of significant stoppages recorded each month was extracted and plotted against the corresponding monthly average SGC and SCC values. Table 7 that follows presents the values of monthly stoppages correlated with the average values SGC and SCC of each month.

The resulting analysis revealed a positive correlation between the frequency of stoppages and both SGC and SCC. Months characterized by a higher number of stoppages also exhibited higher values of specific energy consumption. This pattern indicates that frequent interruptions in operation negatively affect the thermal stability and efficiency of the VRM system. On Figures 9 and 10 are illustrated the graphs of stoppages against averages SGC and SCC, respectively.

When stoppages occur, the mill and auxiliary systems (such as the hot gas generator and fan units) undergo repeated heating and cooling cycles. Each restart requires additional energy input to restore the desired process temperature and system pressure balance. Moreover, material accumulation and inconsistent feed flow following stoppages lead to unstable grinding conditions and incomplete heat recovery, which further increase gas consumption. Consequently, minimizing unscheduled stoppages is crucial for maintaining consistent energy performance. Stable operation ensures steady-state conditions within the mill, better utilization of the supplied thermal energy, and reduced specific calorific consumption. This correlation confirms that operational reliability

■ **Table 6** Average values of SGC and SCC of cement 3X and Falcon

	APRIL 2025		MAY 2025		JUNE 2025		JULY 2025		AUGUST 2025	
	3X Cement (42.5R)	Falcon (32.5R)	3X Cement (42.5R)	Falcon (32.5R)	3X Cement (42.5R)	Falcon (32.5R)	3X Cement (42.5R)	Falcon (32.5R)	3X Cement (42.5R)	Falcon (32.5R)
AVG. SGC (m^3/MT)	1.18	2.67	1.74	3.74	1.22	3.69	1.67	4.04	2.57	4.36
AVG. SCC (kJ/MT)	42008	95052	42008	133144	42008	131364	42008	143824	42008	155216
Avg. Production (MT)	2106	2576	2215	2576	2169	1698	2036	1900	2057	2546

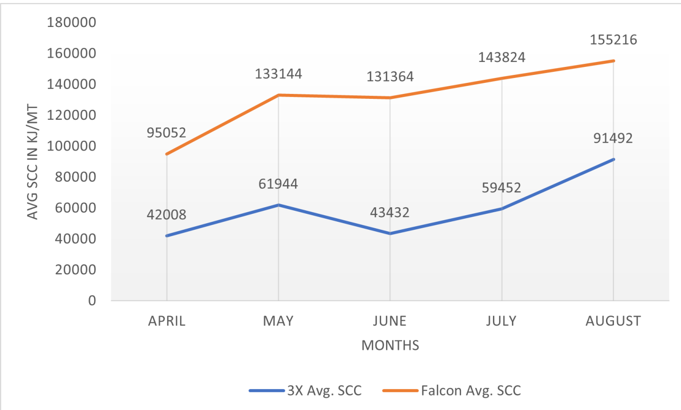


Figure 8 Graph of average SGC of 3X versus Falcon.

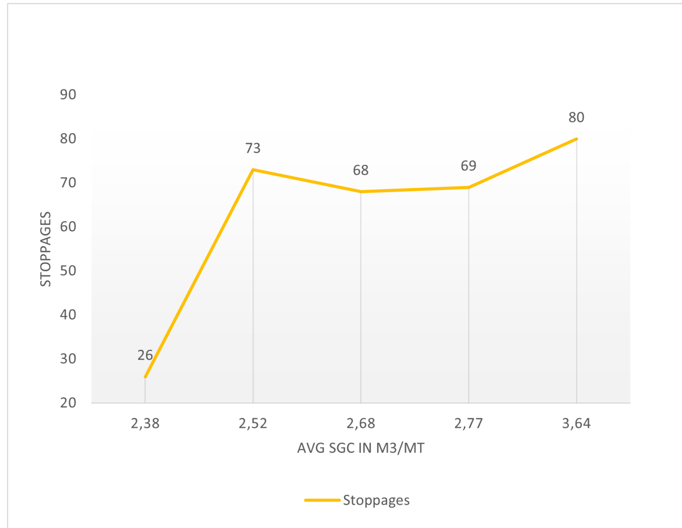


Figure 9 Graph of stoppages versus average SGC.

■ **Table 7** Values of monthly stoppages

	APRIL 2025	MAY 2025	JUNE 2025	JULY 2025	AUGUST 2025
Stoppages	26	73	68	69	80
Avg. SGC (m^3/MT)	2.38	2.52	2.68	2.77	3.64
Avg. SCC (kJ/MT)	84728	89712	95408	98612	129584

is a critical factor in energy optimization and should be closely monitored in the overall performance improvement strategy of the cement grinding unit.

Actionable solutions to reduce calorific consumption

Based on the analyses performed through trend evaluations and correlation studies, several actionable solutions have been identified to address the main causes of high SCC in the VRM. The results showed that the principal contributors to high SCC include high moisture content of pozzolana, frequent operational stoppages, fluctuating feed rate, and low calorific value of the fuel. Other secondary factors such as heat losses to the surroundings, incorrect fuel–air ratio in combustion, inaccurate measurement and energy balance, and ambient humidity variations were also found to contribute to a lesser extent. The following points present detailed, practical, and technically justified solutions aimed at minimizing these inefficiencies and improving the overall thermal performance of the VRM. Arranged in order of priority, the first three solutions should be looked upon first since they have the highest impact.

1. Reduction of moisture content in raw materials

   High moisture content, especially in pozzolana used for the production of Falcon cement, was identified as the most significant cause of increased calorific consumption. Moist pozzolana requires additional energy for drying inside the mill, which increases fuel demand and decreases overall thermal efficiency.

   - To mitigate this, it is recommended to adopt proper raw material handling and storage techniques. During the rainy season, pozzolana stockpiles should be covered with waterproof tarpaulins, and drainage systems should be improved to prevent water accumulation. Materials should be stored on raised platforms or concrete pads to avoid direct contact with wet ground.
   - Additionally, segregation of high-moisture batches and pre-drying them using waste hot gases from hot gas generator before feeding the mill can significantly reduce drying energy requirements.
   - Implementing a routine moisture monitoring program with portable moisture meters will help maintain consistent material quality.
   - In the long term, investing in a dedicated pre-drying unit or installing a covered pozzolana storage facility would stabilize raw material conditions throughout the year, thereby ensuring steady energy consumption.

2. Minimization of operational stoppages

   Operational stoppages were found to have a direct positive correlation with SCC, as frequent interruptions result in repeated reheating cycles, unsteady mill operation, and fuel wastage during restarts. Reducing stoppages therefore presents a major opportunity for energy savings.

   - To achieve this, X cement factory should implement a preventive maintenance program focusing on critical

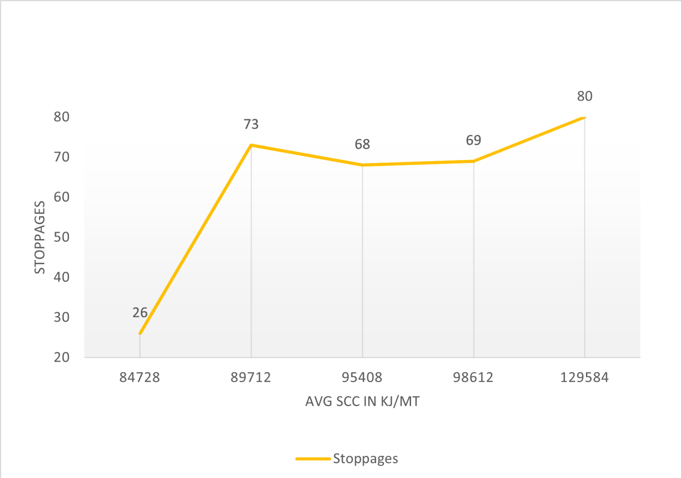


Figure 10 Graph of stoppages versus average SCC.

equipment such as the mill feed system, hot gas generator, and burner assembly. Maintenance teams should carry out pre-shift inspections to detect potential faults early.
- Furthermore, introducing a stoppage log system to categorize stoppages as "avoidable" or "unavoidable" will make it easier to identify recurring mechanical or operational failures.
- Availability of essential spare parts and improved coordination between production and maintenance teams will reduce repair times.
- Training operators on quick fault response and performing root-cause analysis after major stoppages will also help minimize downtime. Overall, reducing stoppages will lead to smoother operation, higher throughput, and more efficient fuel utilization.

3. Stabilization of feed rate

The correlation results revealed that fluctuations in feed rate significantly affect calorific consumption. When the feed rate is unstable or lower than the design capacity, the energy supplied by the hot gases is not efficiently utilized, leading to an increase in SCC.

- To stabilize the feed rate, operators should adhere to standard operating procedures with clearly defined target feed setpoints. The use of automated feeders with feedback control can help maintain steady feeding, while interlocks and alarms can alert operators of deviations from the target. Regular calibration of feed control equipment should also be ensured.
- In the medium term, installation of a surge bin or buffer hopper before the mill could help smoothen feed variations due to upstream fluctuations.
- Training operators on the importance of consistent feed rate and monitoring performance indicators such as feed rate variance (coefficient of variation) will also promote operational stability. Stable feed rate operation ensures optimal use of supplied heat, reducing the SCC and improving product quality consistency.

4. Improvement of fuel quality and combustion efficiency

Low calorific value fuel was another major cause of high SCC. When the fuel used is of lower calorific value, a higher volume is required to generate the same thermal output, increasing overall energy costs.

- To mitigate this, a fuel quality control procedure should be established. Fuel suppliers should provide certificates of calorific value, and random fuel sampling and laboratory testing should be done periodically to ensure consistency.
- Additionally, burner tuning and combustion control should be improved. The correct fuel–air ratio must be maintained to ensure complete combustion and prevent energy losses.
- Installing or optimizing oxygen (O_2) and carbon monoxide (CO) monitoring systems can help operators maintain combustion efficiency within target limits. These measures will enhance fuel utilization, lower specific gas consumption, and consequently reduce SCC.

5. Reduction of heat losses and improvement of system insulation

Although heat losses were not among the top four causes, they contribute to cumulative inefficiencies that raise calorific consumption. Uninsulated ducts, leaks in hot gas lines, and radiation losses from high-temperature surfaces can significantly affect thermal performance.

- Regular thermal audits using infrared thermography can identify high heat loss zones.
- Installing or replacing insulation materials on ducts, pipes, and cyclones, as well as repairing leaks and damaged seals, will help retain more heat within the system.
- Moreover, the use of heat-resistant coatings on exposed metal surfaces can further minimize radiation losses.
- Periodic inspection and maintenance of insulation systems should be institutionalized as part of the energy management plan.

6. Enhancement of measurement and process control systems

Accurate measurement and process control are essential for continuous energy optimization. Lack of precise energy balance and inadequate monitoring can mask inefficiencies and delay corrective actions.

- It is recommended to install additional sensors to measure key parameters such as gas flow rate, fuel flow, temperature, and raw material moisture.
- The use of a data logging system or integration with the existing SCADA network will allow for real-time performance monitoring.
- Furthermore, conducting periodic energy and heat balance studies will provide a quantitative understanding of losses and efficiency levels, helping management make informed decisions.

Better measurement and automation will ensure tighter control of process variables such as feed rate, gas temperature, and air-to-fuel ratio, ultimately stabilizing operation and reducing SCC.

7. Implementation of predictive maintenance and training programs

- To ensure sustained improvement, the company should transition from reactive maintenance to a predictive maintenance approach. Techniques such as vibration analysis, thermography, and oil condition monitoring can detect potential failures before they occur, minimizing unexpected stoppages and associated energy losses.
- Operator training should also be emphasized. Training programs should cover energy-efficient operational practices, the importance of maintaining stable feed, quick fault diagnosis, and response procedures. Empowered and skilled operators can significantly contribute to maintaining efficient energy use.

8. Continuous energy monitoring and management

   Finally, establishing a continuous energy management system will consolidate all the above actions. Setting monthly energy targets for SCC and SGC, conducting performance reviews, and rewarding teams for achieving energy reduction goals will help sustain progress. Introducing Key Performance Indicators such as SCC (kJ/MT), number of stoppages, average feed rate, and moisture content of raw materials will enable management to track the impact of interventions. Over time, this data-driven approach will promote a culture of continuous improvement and accountability in energy management.

CONCLUSION

This paper studied the factors influencing calorific consumption of a vertical roller mill (VRM) and solution proposals to reduce it at X cement factory sought to evaluate and improve the calorific performance of the VRM unit used for cement grinding and drying. Data were collected over a period of five months (April 2025 to August 2025) from the plant's operational records. Analytical techniques were applied to determine the relationships between calorific consumption and key process parameters, including feed rate, moisture content, and stoppage frequency. The findings revealed that the specific calorific consumption (SCC) showed a continuous increasing trend over the analyzed period, indicating deteriorating energy efficiency. The correlation analysis established that unstable feed rates, high moisture content of raw materials, and frequent stoppages were the main factors responsible for elevated calorific consumption. Moreover, cost analysis demonstrated that months with higher SCC corresponded to significant increases in fuel costs, confirming the direct economic impact of poor energy performance.

In conclusion, this study successfully met its objectives by identifying the principal factors affecting calorific consumption in the VRM system at X cement factory and proposing practical solutions for their mitigation. It demonstrated that energy optimization in cement production is achievable through a combination of data-driven analysis, operational discipline, and continuous performance monitoring. Beyond the economic benefits, implementing these measures will also strengthen the company's environmental stewardship by reducing fuel usage and CO_2 emissions. To implement the best solution to reduce calorific consumption, further research could explore the use of waste heat recovery systems to utilize exhaust gases, evaluate alternative fuels with lower carbon intensity, and implement computational simulations for process optimization.

Ethical standard

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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