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MK3 Kiln Built With Construction and Demolition Waste to Mitigate PM2.5 and PM10 in the Production of Handmade Bricks in Peru

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MK3 Kiln Built with Construction and Demolition Waste to Mitigate PM2.5 and PM10 in the Production of Handmade Bricks in Peru

Abstract. The study focuses on the design of the MK3 kiln as an eco-friendly solution to mitigate the pollution of (PM2.5 and PM10) generated by artisanal brick kilns. The MK3 kiln consists of three chambers constructed with construction and demolition waste (CDW), interconnected by lower ducts that aid in the continuous flow of heat and filter pollutants. Each kiln has a 5 cm opening in the dome to accommodate a copper industrial torch with a power of 1080 BTU/h, equivalent to 0.32 kW. Additionally, a 220V axial fan is installed in the chimney to supply the necessary air to the kilns through upper ducts, allowing complete combustion during the brick baking process. As a result, PM2.5 was measured at a quantity of 23 $\mu g/m^3$, and PM10 emissions at 90 $\mu g/m^3$, both of which do not exceed Environmental Quality Standards (ECA). Regarding the brick baking process, heat is recovered from the "combustion kiln" to the "recovery kiln," reaching a temperature of 70.8 °C through the cogeneration system. Furthermore, the brick baking process reaches a temperature of 746.3 °C over a period of 4 hours (240 minutes), ensuring high levels of strength. Finally, the energy of the combustion process is continuously optimized, presenting an efficient alternative by using propane gas as fuel, which is versatile for brick baking.

Key words: Artisanal brick kiln, PM10 and PM2.5, heat recovery, construction and demolition waste, cogeneration system.

1 Introduction

Artisanal brick production poses a global environmental challenge. Particulate matter PM2.5 and PM10 emissions from this industry account for a quarter of global emissions. In addition, more than 80% of the urban population is exposed to harmful levels of these emissions, which negatively affects air quality. Therefore, it is crucial to address this issue to protect people's health and improve air quality in affected urban areas [1]. In Mexico, the production of handmade bricks using traditional kilns is common in construction, but has a negative environmental impact due to its energy inefficiency and the use of highly polluting fuels. On a global scale, Asian countries lead clay brick production, generating 1.5 billion units and less than 10% use modern mechanized technology [2]. Studies have verified that traditional brick manufacturing emits pollutants into the air, contributing to global pollution. These studies have analyzed these gases at different temperatures and their relationship to clay properties, demonstrating that input/firing variables, chemical reactions, and thermodynamic processes in the kiln chamber affect both brick and pollutant emissions [3]. However, in 2019, the World Health Organization (WHO) reported an alarming situation: almost 99% of the world's population is affected by PM2.5 and PM10 particulate pollution, causing approximately 6.7 million premature deaths per year [4]. Moreover, in artisanal brick manufacturing, 26% of workers were found to have cough, 38% suffered from chronic obstructive pulmonary disease (COPD), 53% experienced irritation and 15.33% suffered from hypertension [5].

During 2019, a significant increase of 87.5% was recorded in the city of Nepal, located in the South Asian region. Currently, around 1,000 brick kilns are operating in the city, which consume 70% coal as fuel. These kilns are responsible for an annual production of approximately 6 billion bricks, which represents 1.81% of the region's total. Unfortunately, this activity has a very significant negative impact on air quality [6]. Therefore, efforts have been made in Mexico to counteract the impacts caused by brick manufacturing by implementing advanced technologies and conducting research aimed at improving quality in this industry. It is estimated that there are about 17,000 brick kilns in the country, of which less than 3% are industrialized, 22% belong to the traditional campaign category and 75% are traditional fixed kilns [2]. There are approximately 2,500 brick kilns in operation in Peru, of which it is estimated that between 40% and 50% are artisanal kilns with old rural infrastructure. These kilns lack control mechanisms to mitigate high emissions and have low efficiency in brick production, which generates more environmental pollution [7]. In response to this problem, the MK3 kiln is presented as a solution to the environmental challenges associated with brick firing.

This study investigated its performance in a typical firing process, performing experiments under normal operating conditions and analyzing the energy balance. The results revealed an efficiency of up to 44.09 % in the MK3 kiln, thus mitigating pollutants. These findings support its viability as an efficient and sustainable option for brick production [8]. In addition, construction and demolition waste (CDW) was used for the implementation of the kiln. CDW accounts for 35% to 45% of global material streams for reuse in construction. It is crucial to subject CDW to specific tests and requirements using appropriate technologies to meet standards in new construction, thus promoting a circular economy [9]. Similarly, in Egypt, construction material waste accounts for 40% of the total cost, which is equivalent to 16% of the total construction cost including labor. This highlights the importance of reusing these types of materials in construction [10].

The objective of this study is to reduce PM2.5 and PM10 pollutants in Peru, specifically in the department of Junín, in the city of Huancayo (Annex of Cullpa Baja). It addresses the negative emissions caused by traditional ovens that use firewood, eucalyptus branches, tires and solid waste, thus impacting air quality and human health.

2 Materials and Methods

To initiate the experimental process, data was collected, and the construction of the MK3 Kiln was prepared to adapt the traditional brick baking kiln. The primary objective is to mitigate pollutants in artisanal brick production and analyze heat recovery through the cogeneration system. Through this analysis, the goal was to create an economical alternative with advantages that reduce environmental impact, energy consumption, and risks to human health.

2.1 MK3 furnace Design Features

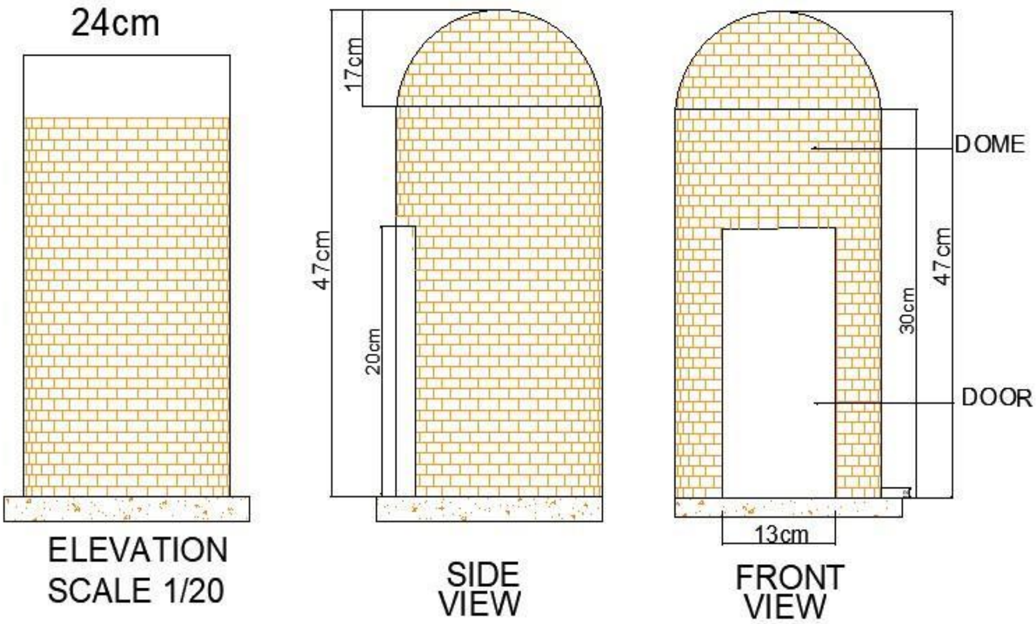

Fig. 1. Dimensions of the furnaces of the MK3 Furnace.
Source: Own elaboration.

Figure 1 shows the construction of each oven, which has a height of 47 cm, has walls 30 cm long with a wall thickness of 4 cm. The dome has a height of 17 cm with a thickness of 4 cm. The entire design of the MK3 furnace is constructed using construction and demolition waste (CDW) and refractory cement, resulting in better thermal insulation and heat resistance, thereby reducing heat loss to the surroundings.

2.2 MK3 Furnace Built Design

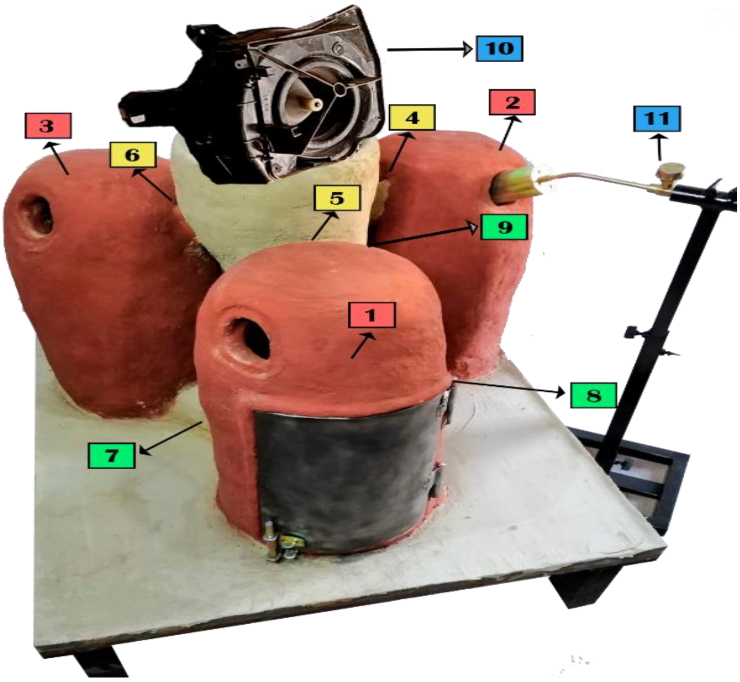

Fig. 2. Design of the MK3 furnace.
Source: Own elaboration.

In figure 2, three interconnected ovens are seen. The first "Kiln (1)" is used for the combustion and firing of bricks. The second "Kiln (2)" is used for energy recovery through cogeneration and pollutant filtration. The third "Kiln (3)" is responsible for loading the raw bricks and unloading the fired bricks. The third loaded kiln becomes a recovery kiln, while the previous recovery kiln becomes a combustion kiln, allowing a continuous cogeneration process.

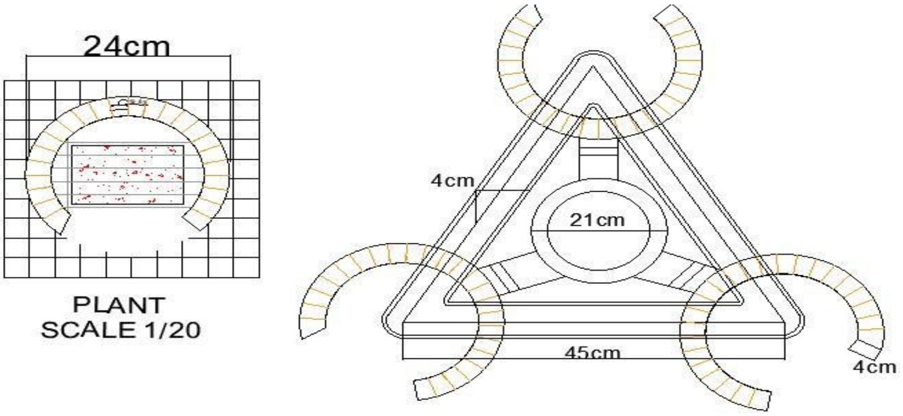

Fig. 3. Dimensions of the ducts connecting the 3 furnaces.
Source: Own elaboration.

In figure 3, you can see the lower ducts 7, 8 and 9 connect the three ovens 4 cm high and wide. They allow heat flow and are equipped with regulating dampers, as are the chimney ducts. The kiln chimney is 21 cm in diameter and 29 cm in height, which is connected to the kilns by ducts, and has a 220 V axial fan, which is installed at the top of the chimney, having a maximum speed of 5.8 m/s of oxygen that will flow through the upper conduits (4), (5) and (6), everything depends on the furnace being in the burning process to open the gates of its lower conduit and give access to the necessary oxygen and achieve complete combustion

As shown in figure 2, each of the kilns (1), (2) and (3) has an oxygen continuous flow inlet duct: the upper duct (5), (4) and (6), respectively. This duct allows oxygen from the air to enter the kilns for combustion of the combustion process during brick firing. In addition, the kilns are connected through lower ducts that facilitate the flow of heat by cogeneration. The furnaces (1) and (2) are connected through the bottom duct (8). Ovens (2) and (3) are connected through the lower duct (9). Finally, ovens (3) and (1) are connected via the bottom duct (7). In addition, an axial fan (10) is provided to facilitate the flow of oxygen, while the industrial torch (11) is used for the combustion of the burner by means of propane gas.

2.3 Brick Firing Process

An industrial copper torch with a nozzle diameter of 5 cm is used to start the firing process. It is powered by propane gas, which has a power of 1080 BTU/h, equivalent to 0.32 kW. The torch is introduced into the furnace through an opening in the upper part, specifically in the domes. This industrial copper torch, designed and manufactured locally, improves gas combustion.

The process starts in the kiln (1), where the bricks are burned using the industrial torch (11). Oxygen from the air is introduced through the upper duct (5) to raise the temperature to 746 °C, ensuring proper firing of the brick. Then, the oxygen flow moves through the lower duct (8) to the kiln (2), where thermal energy is recovered and PM 2.5 and PM10 pollutants are filtered out. Meanwhile, in the Kiln (3), the raw bricks are loaded. Once the Kiln (1) has completed firing, the process continues in Kiln (2) using the recovered energy. In addition, the lower duct (8) conveys the heat flow to the Kiln (3), allowing energy recovery and filtration of contaminants. This loading and firing process is repeated successively in the Furnace (1) and in the subsequent furnaces.

3 Results

The results of this project have significantly contributed to the understanding of artisanal brick kilns. Through extensive experiments and analysis, fundamental findings have been identified that highlight the advantages of the MK3 kiln design. These advantages encompass the brick baking process, heat recovery, reduction of pollutant emissions, and a notable improvement in the quality of the brick. The results underscore the benefits of the MK3 kiln design, such as:

3.1 Brick Baking in the MK3 Kiln

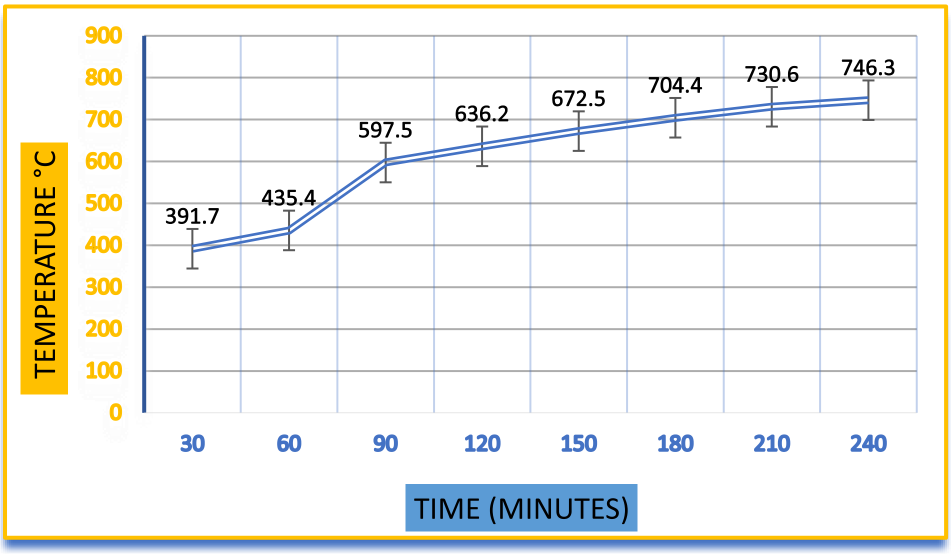

Fig. 4. Result of oven temperature and baking time.
Source: Own elaboration.

In figure 4, the tests carried out show a progressive increase in the temperature inside the kiln during the brick firing process. At 30 minutes the temperature reached 391.7°C, at 60 minutes it was 435.4°C, at 120 minutes it reached 636.2°C and at 240 minutes, which marks the end of the brick firing process, a temperature of 746°C.

3.2 Cogeneration System in the MK3 Kiln

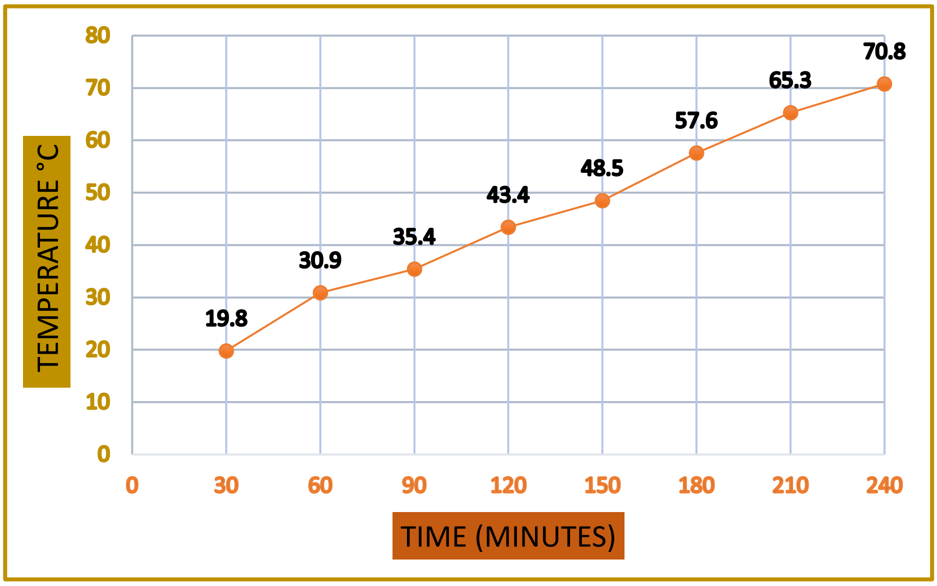

Fig. 5. Result of heat recovery in the brick baking process.
Source: Own elaboration.

One of the notable benefits of the MK3 oven is its cogeneration capacity, the heat generated by the first oven is channeled to the second oven through the lower ducts. This reduces fuel consumption as it is preheated before use. As shown in Figure 5, 30 minutes into the brick firing process, the second kiln registers a temperature of 19.8°C. After 120 minutes, the temperature reaches 43.4°C and at 240 minutes, it measures a temperature of 70.8°C. These results confirm the operation of the heat cogeneration system through the ovens, which have a continuous process.

3.3 PM2.5 and PM10 contamination during brick firing

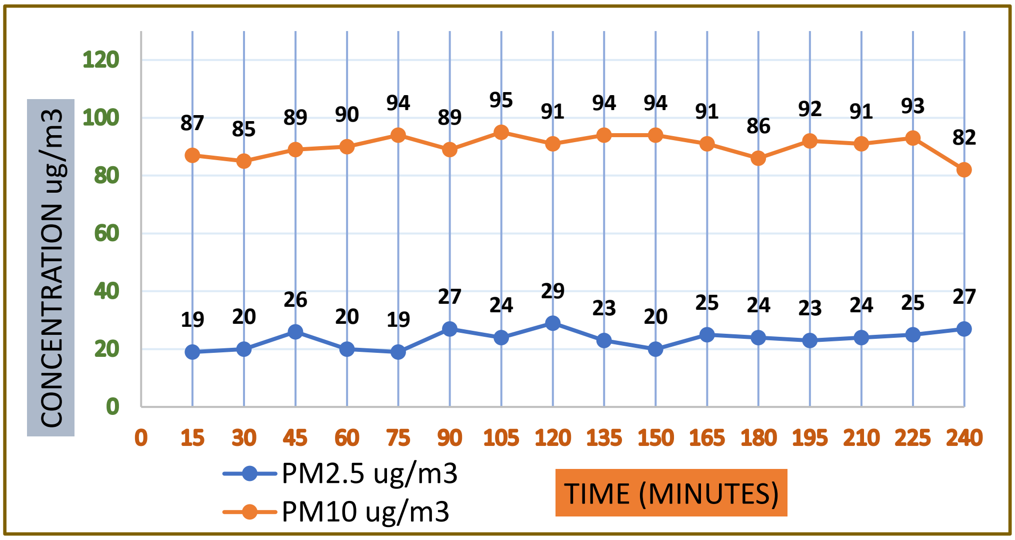

Fig. 6. Results of PM 2.5 and PM10 emissions from the MK3 furnace
Source: Own elaboration.

Table 1. Supreme Decree N° 003-2017-MINAM - PERU- Environmental Quality Standards (ECA) of Air are approved [11].

Parameters	Period	Value [µg/m3]	[µg/m3] Evaluation Criteria	Method of analysis
Particulate matter with diameter. less than 2.5 microns (PM2.5)	24 hours	50	NE more than 7 times a year	Inertial separation/filtration Annual 25 Annual arithmetic mean (Gravimetry)
	Annual	25	Annual arithmetic mean	
Particulate matter with diameter. less than 10 microns (PM10)	24 hours	100	NE more than 7 times a year	Inertial separation/filtration Annual 50 Annual arithmetic mean (Gravimetry)
	Annual	50	Annual arithmetic mean	

Source: Peru (Ministry of Environment). Approval of Environmental Quality Standards (ECA) for Water and complementary provisions.

Table 1 shows the guidelines established in Supreme Decree No. 003-2017-MINAM - PERU, PM2.5 levels should not exceed 50 $\mu g/m^3$ and PM10 levels should not exceed 100 $\mu g/m^3$. m3. The results obtained, which can be seen in Figure 6, indicate the obtained levels of PM2.5 at 23 $\mu g/m^3$ and PM10 levels at 90 $\mu g/m^3$, which do not exceed environmental quality standards. Furthermore, this result is obtained by the brick firing system of the MK3 oven and the fuel used such as propane gas, which does not emit particles into the environment abruptly, but rather tends to settle and adhere to the lower ducts of the MK3 oven.

3.4 Brick Obtained at the End of the Firing Process in the MK3 Kiln

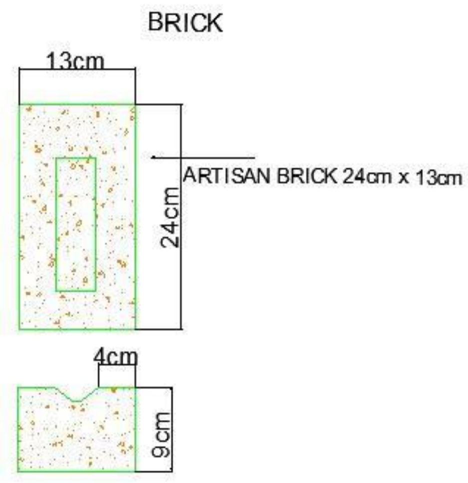

Fig. 7. Details of the design of the brick plan for use in the MK3 kiln.
Source: Own elaboration.

Fig. 8. Results obtained in the brick firing process in the MK3 kiln.
Source: Own elaboration.

It has been shown that the brick firing process achieves excellent homogeneity, which is crucial to reflect the quality of the process and the results obtained. In figures 7 and 8, homogeneous firing is observed, which implies uniform heating throughout the MK3 kiln, avoiding temperature variations and guaranteeing constant quality in terms of resistance, durability and appearance of the brick. In addition, the control mechanism ensures uniformity and optimization of the firing process, allowing adjustments to ideal conditions and ensuring the proper treatment of each brick.

3.5 Study of the Relationship between Brick Kilns and the Local Community: Population Survey

As a result of surveys conducted among the population of Cullpa Baja in the city of Huancayo - Peru, the following data were obtained:

Table 2. Population survey of brick kilns.

	Yes		No	
Questions	Quantity	%	Quantity	%
Do you think smoke emissions from brick kilns can affect air quality in your locality?	18	90%	2	10%
Have you experienced any health problems such as dry cough, bronchitis, respiratory problems, pulmonary fibrosis that may be related to brick kiln emissions?	14	70%	6	30%
Do you think the government should implement stricter regulations to control emissions from brick kilns?	19	95%	1	5%
Do you think it is important to promote environmental awareness and education among brick kilns to reduce their environmental footprint?	20	100%	0	0%
Would you like to receive information on more sustainable and environmentally friendly alternatives in brick production?	20	100%	0	0%

Source: Own elaboration.

Table 2 shows the results obtained from a survey on brick kilns and their environmental impact in the town. Several questions were asked related to smoke emissions from brick kilns, associated health problems (dry cough, bronchitis, respiratory problems, lung fibrosis), government regulations, environmental awareness and promotion of sustainable alternatives in brick production. The data shows the percentage of affirmative and negative responses for each question. Most respondents are concerned about air quality due to emissions from brick kilns and support implementing stricter regulations. In addition, there is strong support to promote environmental awareness and interest in receiving information about more environmentally friendly alternatives in brick manufacturing and being able to provide guidance to raise awareness about the importance of the pollutants emitted by brick factories, how it affects their health and the criteria they must follow to protect and take care of themselves at work.

4 Discussion

The analysis of the MK3 kiln design focuses on mitigating PM2.5 and PM10 pollutants, as well as on heat recovery for reuse in the baking process. It stands out for its excellent temperature control and regulation, enabling heat transfer from the first kiln to the second through cogeneration. This heat transfer helps reduce fuel usage, resulting in lower energy consumption and a smaller environmental footprint compared to conventional brick baking methods. On the other hand, quick baking in an electric kiln can expedite the process. Similarly, it is essential to assess the energy consumption required to reach and maintain the necessary high temperatures. Striking a balance between heat recovery and the expected outcomes in terms of brick quality is crucial [12]

The pollutants generated by the concentration of particulate matter have serious consequences on the health of neighbors living near brick kilns [13]. Brick kilns emit pollutants depending on several factors, such as firing duration, temperature level, fuel type and kiln design. When analyzing artisanal kilns, their emissions reflect the technology employed. The more they are analyzed in terms of these factors, the more productive they could become [14]. This is why the MK3 kiln is the best alternative to reduce the negative environmental impact and improve the economic and social aspects. The MK3 kiln was built using construction and demolition waste (CDW) to promote the circular economy and the reuse of materials. In Spain, initiatives are being taken for a more productive and sustainable use of CDW, aiming at an innovative and sustainable management of these materials [15]. In Peru, a CDW management project is being implemented based on the hierarchy principle, which involves a detailed analysis of the existing regulations, instruments and infrastructure for the current management of CDW. Subsequently, the construction of a CDW valorization plant is proposed, determining the optimal location by means of a multi-criteria analysis. In addition, the amount of CDW generated is estimated by means of linear regression that considers population factors and economic flows, with the objective of promoting its reuse and utilization.

5 Conclusion

In conclusion, the MK3 kiln, constructed with construction and demolition waste (CDW), exhibits high durability and features thermal insulation that facilitates the brick baking process. It also mitigates PM2.5 and PM10 pollutants, offering a superior technological proposal with impacts across various sectors, including social, economic, and environmental aspects. Firstly, measurements taken in the MK3 kiln revealed PM2.5 levels at 23 $\mu g/m^3$ and PM10 levels at 90 $\mu g/m^3$, both of which do not exceed environmental quality standards (ECA). Secondly, the cogeneration system generated by brick baking in "kiln (1)" and transferred through lower ducts to "kiln (2)" resulted in 70°C of recovered heat, representing a reduction in heat losses for reuse, thereby sustaining the continuous brick baking process across the three kilns. Thirdly, as the final product, the baked brick was obtained with a temperature of 746.3 °C in 4 hours, achieving high levels of strength. Finally, the MK3 kiln emerges as a viable alternative to replace inefficient and polluting traditional kilns used in brick production, thereby improving the quality of life for society and the environment.

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