JST: Engineering and Technology for Sustainable Development
Volume 33, Issue 5, November 2023, 057-064

Evaluating the Energy Efficiency and Environmental Impact of a Multi-Chamber Brick Kiln in Vietnam

Pham Thai Son[1], Truong Tuan Ngoc[1], Nguyen Van Thu[2], Nguyen Xuan Quang[1]*
[1]*School of Mechanical Engineering, Hanoi University of Science and Technology, Ha Noi, Vietnam*
[2]*Phu Tho Vocational College of Technology and Agriculture and Forestry, Phu Tho Province, Vietnam*
[*]*Corresponding author email: quang.nguyenxuan@hust.edu.vn*

Abstract

Brick production is an essential component of the construction industry, contributing significantly to the development of infrastructure and housing worldwide. This study evaluates the energy efficiency and environmental impact of a multi-chamber brick kiln in Vietnam. The study was conducted through a detailed field survey of the kiln, which included measurements of energy consumption and pollutant emissions. The results show that the kiln has a moderate level of energy efficiency, as indicated by the specific energy consumption of 2,035.1 kJ / kg output brick. However, the kiln also produces pollutants, including SOx, CO, and NOx. The study provides recommendations for improving the kiln's energy efficiency based on the results of the energy analysis. Overall, this study highlights the importance of improving the energy efficiency as well as the environmental performance of a Multi Chamber Brick Kiln in Vietnam and provides valuable insights for policy-makers and industry stakeholders.

Keywords: Energy efficiency, specific energy consumption (SEC), energy analysis, brick kiln, pollutant emission, environmental impact.

1. Introduction

The production of bricks requires large amounts of energy, and the process can lead to significant environmental impacts such as greenhouse gas emissions, air pollution, and depletion of natural resources [1-5]. Therefore, there is a growing need to focus on energy efficiency in brick production to reduce its environmental impact and promote sustainable development. Energy efficiency in brick production refers to the use of efficient technologies and practices that reduce the amount of energy required to produce bricks while maintaining or improving the brick quality. In recent years, various initiatives have been taken to promote energy-efficient brick production, including the development of new technologies, energy management systems, and policies aimed at reducing energy consumption in the sector.

In order to have energy saving in brick production, the firing technology is changed from the intermittent process into continuous process. Some well known firing technologies for brick production include: Hoffman kiln [1-3], Vertical shaft brick kiln (VSBK) [1, 3], Tunnel kiln [1, 2], and Multi-chamber brick kiln (MCBK) [4, 5]. These technologies offer significant potential for reducing energy consumption in brick production while improving efficiency and reducing environmental impact. However, their adoption and implementation depend on various factors such as cost, availability of resources, and local regulations and policies. Also, a specific practical application for each brick kiln type affects the energy consumption of the brick production process. A comprehensive approach that considers all of these factors, however, is out of the scope of this study. Instead, this work focuses on the specific energy consumption of brick kilns and the detail energy balance of a multi chamber kiln that is newly developed in Vietnam.

The specific energy consumption (SEC) of a brick kiln is a parameter that measures the energy performance of the kiln. The SEC is defined as the amount of energy required (input) to produce one unit of product (output), typically in brick making process it is measured as kJ/kg bricks. The SEC of brick kilns reported in the literature can vary depending on the design and operating conditions of the kiln, fuel used, type of soil used, brick shape and size, brick forming technology.

It is important to note that the SEC value reported in literature [2, 6] are specific to brick kilns in specific countries and may not be directly applicable to other regions or countries with different operating conditions and raw materials. However, these values can provide valuable insights into the energy efficiency of brick kilns and help identify

ISSN 2734-9381
https://doi.org/10.51316/jst.170.etsd.2023.33.5.8
Received: August 24, 2023; accepted: October 26, 2023

opportunities for improvements and optimization in the manufacturing process.

Brick firing process, in general, must follow four main periods, including drying, preheating, firing and cooling, in a sufficient duration and at a specific temperature range for each period. In the intermittent brick kilns, all of these four periods occur in one batch without efficient usage of the remaining heat energy between periods. For the continuous kilns, the firing process will be arranged in the way that the heat energy from one period could be used for other periods continuously. By arranging those periods into four zones, i.e., drying, preheating, firing and cooling, hot brick in a cooling zone will be used to supply heat to the firing zone. Remaining heat from firing period in the form of hot flue gas will be used in the preheating zone and then the drying zone before going to the chimney as cool stack gas. In tunnel kilns, zones are fixed in one area along a long tunnel and bricks are arranged on a wagon will be moved on the rail through those zones. In other principles, such as Zigzag kilns, Hoffmann kilns, multi chamber kilns, the arrangement is that the position of the bricks are fixed at one place and zones are moved around.

Multi Chamber Brick Kilns (MCBK) are quite rarely used for brick making process due to its complicated structure and operation. However, it has an advantage of easier adjusting temperature and remaining time of brick in each chamber by adding more fuel in each chamber so that it could be used to produce other difficult type of rough ceramic such as tiles, shaped brick. In this study, the experiment has been done in a new design of MCBK which is creating a channel for that the hot air when going through cooling zone could be used partly for drying purpose. The kiln is designed and constructed based on a project [7] named "Research on design and construction of Multi Chambers Brick Kiln for energy saving and environmental protection to produce rough ceramic in Vietnam" funded by Ministry of Education and Training of Vietnam. Location of the kiln is Area 1, Tien Du Commune, Phu Ninh District, Phu Tho Province, Vietnam.

This work focuses on evaluating the energy performance based on determining the SEC of the kiln and conduct the energy analysis for it. The results and corresponding discussion are shown in section 3. Finally, insights and recommendations based on the results obtained in this work are given in the conclusion section.

2. Methods

2.1. Specific Energy Consumption

Specific energy consumption is determined as follows:

$$SEC = \frac{M_{fuel}Q_{fuel}}{M_{brick}}, \; kJ/kg\ brick \qquad (1)$$

wherein,

M_{fuel} : Fuel (coal) required to fire brick (kg fuel)

Q_{fuel} : Gross calorific value of fuel (kJ/kg fuel)

M_{brick}: Mass of brick fired (kg)

The process to calculate the SEC value in this study is as follows:

- Determine coal adding to clay before forming brick; Rate of coal and rate of clay normally adjusted in a conveyor in brick forming process;
- Determine coal adding in the form of coal pieces that are used to adjust the fire during kiln operation;
- Weigh coal pieces and take average value of 5 pieces (those coal pieces are formed from coal briquettes that have similar size and shape);
- Determine amount of fuel used for 1000 bricks and then calculate specific fuel consumption in kg coal/pieces of brick;
- Weigh the bricks to determine brick weight (take an average value of 5 bricks);
- Take coal samples and determine gross calorific value of coal by analysis in laboratory;
- Calculate specific energy consumption by the equations above.

2.2. Energy Analysis for the Brick Kiln

The energy analysis for the kiln operation has been done on the setting time during which the kiln operation is steady (about 2 weeks after the firing starts) with stable firing rate, thus a stable loading and unload brick during continuous operation. The principle of the energy analysis for the brick kiln is the energy balance between energy input (q_1) and energy output q_i (i =2÷7) of the kiln as presented in the Fig. 1.

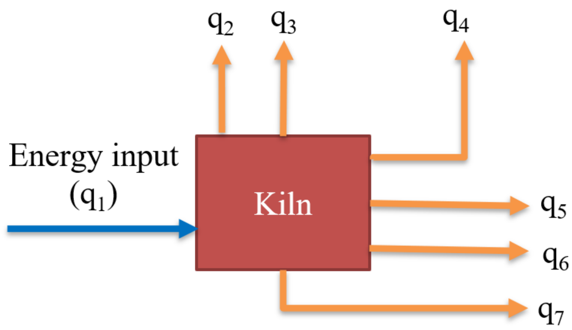

Fig. 1. Energy balance for the investigated multi-chamber brick kiln.

2.2.1. Energy input q_1

During the operation of the kiln, thermal energy is created by the combustion of fuel (coal) in the kiln. The supplied fuel will be used to evaporate water, heat up the kiln structure and green bricks to temperature higher than the ambient temperature, to convert the clay (green brick) to brick.

2.2.2. Heat output

a. Heat used to evaporate moisture content in green brick q_2

The green bricks loaded to the kiln contain moisture. The energy required to evaporate this moisture is calculated as:

$$q_2 = \frac{(BI - BO) \times r}{BO}, \text{ kJ/kg} \quad (2)$$

wherein,

BO: Average amount of bricks produced in 1 hour (kg/h)

BI: Average amount of bricks loaded into the kiln in 1 hour (kg/h)

r: The latent heat of vaporization of water (kJ/kg)

During the continuous operation, certain number of bricks are loaded and unloaded continuously. Thus, the average amount of bricks produced in 1 hour is determined by dividing the total amount of output bricks in one day by 24 hours and the number taken is the average of three days continuously. The average mass of one output brick is about 1,7 kg/piece and the one of the input brick (green brick) is about 2,13 kg/piece. The latent heat of vaporization of water r = 2257 kJ/kg is determined at a pressure of 1 bar and ambient temperature.

b. Heat loss by flue gas q_3

The flue gas coming out of the kiln has temperature higher than the surrounding ambient temperature. This results in the heat loss released to environment. The heat loss due to flue gas is calculated as:

$$q_3 = \frac{m_k \times c_{pk} (T_f - T_a)}{BO}, \text{ kJ/kg} \quad (3)$$

wherein,

m_k: Mass flow rate of flue gas discharged into the surrounding environment (kg/h)

c_{pk}: Specific heat of flue gas (kJ/kg.K)

T_f: Temperature of flue gas (°C)

T_a : Ambient temperature (°C)

Mass flow rate of flue gas discharged into the surrounding environment is calculated as:

$$m_k = B \times \propto \times V_k, \text{ kg/h} \quad (4)$$

wherein,

B: The average amount of coal used in one hour (kg/h)

$\propto$: Excess air coefficient (-)

V^0_k : The theoretical volume of flue gas (m^3)

The average amount of used coal is determined by dividing the total amount of coal used in the firing chamber (including the coal mixed in the green bricks and the coal supplied to the kiln through the suppling holes at the top of the kiln) by the firing duration.

Excess air coefficient $\propto$ is the ratio of the total amount of air used in the combustion to the amount of air needed for the complete combustion of coal. Excess air coefficient is determined by measuring the oxygen concentration C_{O2} in the flue gas as in the following equation:

$$\propto = \frac{21}{21 - C_{O2}} \quad (5)$$

Calculation of the theoretical volume of flue gas V^0_k is based on the component analysis of used coal. The specific heat of flue gas c_{pk} depends on the temperature of the exhausted flue gas. The temperature of flue gas T_f and the oxygen concentration C_{O2} in flue gas are measured by the measuring tools specialized for flue gas. The measuring locations are along the flue gas channels. This measurement avoids the impact of air leakage along the flue gas channels.

c. Heat loss by hot air exhausted from the drying chamber q_4

The air is sucked from the ambience to the cooling chamber. This air is heated up by the energy accumulated in fire bricks and this helps these bricks cool down faster. Then, heated air is supplied to the drying chambers to pre-heat the newly loaded green bricks, which helps reduce the moisture content of green bricks. After this drying stage, the air still has temperature higher than the environment temperature. However, this air also has high moisture content, thus, it is not suitable to use for any stage/chamber of the kiln anymore. This air is discharged to the environment by the circulation fans.

The heat loss due to hot air exhausted from the drying chamber is calculated as:

$$q_4 = \frac{m_{kn} \times c_{pkn} (T_{kn} - T_a)}{BO}, \text{ kJ/kg} \quad (6)$$

wherein,

m_{kn}: Mass flow rate of hot air discharged into the surrounding environment (kg/h)

c_{pkn}: Specific heat of hot air (kJ/kg.K)

T_{kn} : Hot air temperature (°C)

T_a : Ambient temperature (°C)

The mass flow rate of hot air discharged into the surrounding environment m_{kn} is calculated as:

$$m_{kn} = (v_{kn} \times S_{kn} \times \rho_{kn}) \times 3600, \text{ kg/h} \quad (7)$$

wherein,

v_{kn} : Velocity of the hot air discharged into the surrounding environment (m/s)

S_{kn} : Cross-sectional area of the discharged channel (m^2)

ρ_{kn} : Density of the hot air (kg/m^3)

The specific heat of hot air c_{pkn} depends on the temperature of the hot air discharged into the surrounding environment. This hot air temperature T_{kn} is measured at the discharge gate at the end of the primary drying chamber.

d. Heat loss due to the accumulated in the unloaded brick q_5

The fired bricks need to be cooled down to a certain temperature before being unloaded from the kiln. The heat loss due to this cooling down stage of the bricks is calculated as:

$$q_5 = c_{pg}\,(T_g - T_a)\text{ , kJ/kg} \tag{8}$$

wherein,

c_{pg}: Specific heat of bricks (kJ/kg.K)

T_g : Temperature of the unloaded bricks (°C)

T_a : Ambient temperature (°C)

The specific heat of bricks depends on the temperature of the unloaded bricks.

e. Heat loss by radiation and convection through the kiln structure q_6

- *Heat loss through the top of the kiln q_{6t}*

The top of the kiln is constructed as a combination of insulators (mineral wool) and heat resistant concrete reinforced with steel. This reduces heat loss and prevents hot air and flue gas leakage to the environment. The temperature of the top of the kiln is quite high, especially at the location between the firing chamber and the cooling chamber. By measuring temperature at the top of the kiln along the stacked bricks, the heat loss by convection and radiation through the top of the kiln is calculated as:

$$q_{6t} = \frac{k_t \times (T_t - T_a) \times A_t}{BO}\text{ , kJ/kg} \tag{9}$$

wherein,

q_{6t}: Heat loss by convection and radiation through the top of the kiln (kJ/h)

k_t : Heat transfer coefficient at the top of the kiln ($kJ/h.m^2.K$)

T_t : Temperature of the top surface of the kiln (°C)

T_a : Ambient temperature (°C)

A_t : Surface area of the top of the kiln (m^2)

The kiln is divided into 3 zones: the cooling zone, the firing zone and the drying zone. T_t is determined by measuring the temperature at multiple locations at the top of the kiln because this top surface is large, and the temperature may slightly vary (in the range of 30-150K) at different zones (depending on the thickness of the insulation). The T_t value used in the above equation is the mean value of three zones mentioned above.

- *Heat loss by convection and radiation through the kiln wall q_{6w}*

Similar to the convection and radiation loss through top of the kiln, heat loss through the kiln wall is calculated as:

$$q_{6w} = \frac{k_w \times (T_w - T_a) \times A_w}{BO}\text{ , kJ/kg} \tag{10}$$

wherein,

q_{6w} : Heat loss by convection and radiation through the kiln wall (kJ/h)

k_w : Heat transfer coefficient at the kiln wall ($kJ/h.m^2.K$)

T_w : Temperature of the kiln wall (°C)

T_a : Ambient temperature (°C)

A_w : Surface area of the kiln wall (m^2)

It is noted that the temperature of the kiln wall does not vary significantly at different locations/zones.

In total, the heat loss by convection and radiation through the kiln structure is calculated as:

$$q_6 = q_{6t} + q_{6w}\text{ , kJ/kg} \tag{11}$$

f. Unaccounted heat sources q_7

The brick kilns in operation have other heat losses and heat gains that are difficult and/or complex to calculate, as follows.

- *Heat loss due to the heat accumulated in the kiln structures.*

When bricks are unloaded, the structures of the kiln at the location of unloaded bricks have temperature approximately equal to the one of the unloaded bricks. These kiln structures include kiln walls, the bottom of the kiln, flue gas channels, insulation layers at the top of the kiln. The heat accumulated in these structures is not used for any purpose during the brick unloading stage. The duration of this unloading process varies depending on many factors while the temperature distribution inside the kiln structures is complex. Thus, this loss is difficult to determine.

- *Heat loss due to unburned carbon in the ash.*

Depending on the firing process, the structures of the kiln and the working experience of kiln operators, coal may not be completely burned. There is a certain amount of combustible elements that still exist in flying ash and bottom ash. These unburned combustible elements carry a heat loss to the environment. This heat loss is not possible to calculate because it is difficult to make a suitable sample from the huge amount of ash in the kiln for analysis. Moreover, the flow rate of fly ash is difficult to determine.

- *Heat loss due to the formation of carbon monoxide in flue gas.*

The complete combustion of coal will create carbon dioxide. However, in some situations, e.g. insufficiency of air at high temperature, instead of forming carbon dioxide, the combustion process produces carbon monoxide. This incomplete combustion can be considered as a heat loss.

- *Heat loss by the chemical reactions in the brick.*

Heat is required for different reactions occurring during the brick firing process. This includes heat absorbed in the breakdown of clay, the decomposition of carbonates, and heat generated from aluminum oxide transforming reactions. Different methods have been used to investigate and estimate these heats. However, the estimation requires component analysis of clay.

- *Heat is released when water in flue gas condense in the gravity settling chamber or at the bottom of the chimney.*

Gravity settling chamber is the space underground, right below the kiln, used to filter the dust. The flue gas temperature is quite low, about 70 ºC. This is lower than the boiling point of water. At this temperature, a certain amount of steam evaporated in the firing and drying processes will condense. When it is condensed, a certain amount of heat is released to the environment.

- *Heat loss due to unburned coal*

The kiln has a high suction force due to the chimney and the fan system. Thus, a certain amount of coal bran, i.e., coal powder from broken coal, is withdrawn from the kiln while remaining unburned. The amount of this unburned coal is challenging to determine.

- *Heat gained by radiation from the sun.*

Exposed under the sun in clear weather, the structures of the kiln can receive a certain amount of radiation during the daytime. However, this heat gain varies with the environment condition and is difficult to determine precisely.

All unaccounted heat sources will be calculated by subtracting the energy input by the accounted heat losses mentioned above (from sub-section a to e of section 2.2.2).

3. Result and Discussion

Overall results of the energy balance obtained for the investigated multi-chamber brick kiln are shown in Table 1 and Fig. 2. Details of these results are presented in the following paragraphs.

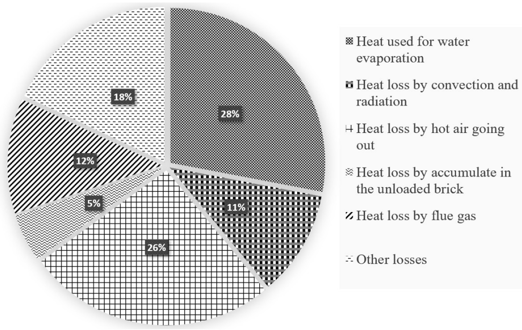

Fig. 2. Distribution of heat loss sources based on the Energy balance for the case of the investigated multi-chamber kiln.

Table 1. Overall results of the energy balance for the investigated MCBK.

Properties	Unit	Value
Input		
Fuel (EI)	kJ/kg	2,035
Output		
q_2	kJ/kg	576.2
q_3	kJ/kg	237.36
q_4	kJ/kg	519.67
q_5	kJ/kg	108.00
q_6	kJ/kg	226.96
Unaccounted heat sources	kJ/kg	437.20

A large portion of the total heat is used for water evaporation of green bricks (28%). This is the useful energy in brick firing process. The drier the input bricks are supplied into the kiln; the less energy is consumed and the firing process could be carried out more easily. Detailed calculations of this heat loss are shown in Table 2.

Regarding the heat loss by flue gas, as shown in Table 3, the excess air coefficient of the investigated kiln is quite high. The oxygen concentration in flue gas is about 16% and the one of carbon monoxide is also quite high as well, around 550 mg/m^3. The existence of carbon monoxide, even though the excess air is high, is the result of bad contact between the air and the coal in the combustion process. This bad contact situation can be worse at night because the kiln operator supplies more coal into the combustion chamber to have a longer break time for sleeping.

Table 2. Heat loss due to moisture content in green brick q_2

#	Properties	Unit	Value
1	Average number of bricks produced in 1 hour	bricks/h	1,471
2	Average weight of a green brick loaded into the kiln	kg/brick	2.13
3	Average weight of a produced brick	kg/brick	1.7
4	Average amount of bricks loaded into the kiln in 1 hour	kg/h	3,138
5	Average amount of bricks produced in 1 hour	kg/h	2,500
6	Amount of water evaporated in 1 hour	kg/h	638
7	Heat loss due to moisture content in green brick q_2	kJ/kg	576.2

Table 3. Heat loss by flue gas q_3

#	Properties	Unit	Value
1	Fuel heating value	kJ/kg	15,211
2	Theoretical air for combustion	kg/kg fuel	7,277.9
3	Oxygen content in flue gas	%	16
4	Actual air for combustion	kg/kg fuel	16.12
5	Actual dry flue gas	kg/kg fuel	21.64
6	Total moisture in flue gas	kg/kg fuel	0.244
7	Flue gas temperature	ºC	74
8	Ambient temperature	ºC	20
9	Heat loss by flue gas	kJ/kg	237.36
10	Heat loss by flue gas	%	11.66

Another large portion of the total heat loss, 25.54%, is caused by the hot air exhausted from the drying chamber (Table 4). Air after being used to cool down hot brick will become hot air that could be used for combustion zone. In the MCBK investigated in this study, the hot air is introduced into new loaded brick for drying purpose. However, the insufficient contact between hot air and green bricks leads to the high temperature of hot air, which is resulted in a high heat loss due to the hot air. Velocity of hot air is measured using pitot tube with the differential pressure measurement between static pressure and dynamic pressure.

As can be seen in Fig. 2, the heat loss due to the accumulated heat in the unloaded brick accounts for 5% of the total energy output. This heat loss is caused by the lack of awareness of the kiln owner/operator. The fired bricks are expected to be cooled down as fast as possible to be unloaded from the kiln. However, the kiln owner/operator makes the fired bricks being cooled by opening the kiln. The fired bricks are exposed to the ambient air while they are still at high temperature. Detail calculations of this heat loss are presented in Table 5.

Table 4. Heat loss by hot air exhausted from the drying chamber q_4

#	Properties	Unit	Value
1	Average amount of bricks produced in 1 hour	kg/h	2,479
2	Hot air temperature	ºC	76.0
3	Ambient temperature	ºC	20
4	Height of hot air channel	m	1.2
5	Width of hot air channel	m	1
6	Velocity of the hot air discharged into the surrounding environment	m/s	5.2
7	Specific heat of hot air	kJ/kg.K	1.009
8	Density of the hot air	kg/m3	1.02
9	Mass flow rate of hot air discharged into the surrounding environment	kg/h	22,801
10	Heat loss by hot air exhausted from the drying chamber q_4	kJ/kg	519.7

Table 5. Heat loss due to the accumulated heat in the unloaded brick q_5

#	Properties	Unit	Value
1	Temperature of the unloaded bricks	ºC	128
2	Ambient temperature	ºC	20
3	Specific heat of unloaded brick	kJ/kgK	1,0
4	Heat loss due to the accumulated heat in the unloaded brick	kJ/kg	108

Table 6. Heat loss by radiation and convection through the kiln structure q_6

#	Properties	Unit	Value
1	Length of the chamber	m	6.0
2	Width of the chamber	m	4.0
3	Height of the chamber	m	2.35
4	Heat transfer coefficient at the kiln wall	kJ/h m^{2}K	30.6
5	Heat transfer coefficient at the top of the kiln	kJ/h m^{2}K	36.0
6	Length of the firing zone	m	4.0
7	Length of the cooling zone	m	12.0
8	Average temperature of outer surface of the kiln wall within the firing zone	ºC	164.4
9	Average temperature of outer surface of the top of the kiln within the firing zone	ºC	163.8
10	Average temperature of outer surface of the kiln wall within the cooling zone	ºC	129.0
11	Average temperature of outer surface of the top of the kiln within the cooling zone	ºC	175.0
12	Ambient temperature near the kiln wall of the firing zone	ºC	29.1
13	Ambient temperature near the top of the kiln within the firing zone	ºC	35.1
14	Ambient temperature near the kiln wall of the cooling zone	ºC	28.5
15	Ambient temperature near the top of the kiln within the cooling zone	ºC	37.7
16	Heat loss by convection and radiation through the kiln wall within the firing zone	kJ/h	77.83
17	Heat loss by convection and radiation through the top of the kiln within the firing zone	kJ/h	74.13
18	Heat loss by convection and radiation through the kiln wall within the cooling zone	kJ/h	173.44
19	Heat loss by convection and radiation through the top of the kiln within the cooling zone	kJ/h	237.25
20	Total heat loss by convection and radiation through the kiln structures	kJ/kg	225.1

The last portion of the accounted heat loss is the one caused by convection and radiation at the top and the walls of the kiln (shown in Table 6). This heat loss may vary due to the two following factors. The first one is the ambient temperature because this heat loss depends on the temperature difference between the kiln's outer surface and the environment. Any change in the ambient temperature has an impact on this heat loss. The second factor is the thickness of the insulation layers. If the insulation thickness is high, the heat conduction transfers from bricks to the kiln surface is reduced, which results in the reduction of the kiln outer surface temperature. Convection and radiation heat loss through the top surface of the kiln can also reduce the temperature of bricks near the top of the brick stack. Thus, most of bricks located at the top of brick stack are under-burned and have brighter color than bricks located at the bottom of the kiln.

For the calculation of the heat loss by radiation and convection through the kiln structure, the temperature of the kiln surface at different locations along and corresponding to the brick stacks inside the kiln, from the end of the cooling zone to the end of the drying zone have been measured. The location between the cooling zone and the firing zone has the highest temperature. The temperature at the drying zone is normally lower than the one of the cooling zone. Table 6 shows the radiation and convection loss associated with the cooling zone and the firing zone. The cooling zone has not only the largest surface area but also a high outer surface temperature (at the top of the kiln). The heat loss in the cooling zone is the highest convection and radiation loss through the kiln structures. The heat loss at the top of the firing chamber is also high and this heat loss can increase if the temperature of the locations near the coal supplying holes rises up, can be up to 350 ºC or even higher in some cases. In order to reduce the heat loss through the top surface of the kiln, the insulation at the top is important. Depending on the management and working experience of each kiln owner, the top insulation can have different thickness, which affects differently to the convection and radiation heat loss.

The unaccounted heat loss is 18.03%. These sources of unaccounted loss are really difficult to determine as the uncertainty of measuring and calculation. Some of them could be recognized by the operator and reduction could be done by experienced operator.

The results on the calculation of the specific energy consumption of the investigated MCBK are shown in Table 7. The SEC of the MCBK investigated in this work is 2,035.1 kJ/kg output brick. This is a moderate value compared to the SEC values of the modern brick kilns (VSBK, Hoffman and tunnel kilns) reported in literature, in the range from slightly below 1,000 to about 3,000 kJ/kg output brick [2, 6].

Table 7: Energy input and SEC

#	Properties	Unit	Value
1	Average amount of bricks produced in 1 day	bricks/day	35,000
2	Average amount of bricks produced in one hours	bricks/h	1458
2	Average weight of a green brick loaded into the kiln	kg/brick	2.13
3	Average weight of a produced brick	kg/brick	1.7
4	Average mass of bricks produced in 1 hour	bricks/h	2,479
5	Fuel heating value	kJ/kg fuel	15,208
6	Amount of fuel needed to fire brick in 1 hour	kg fuel/h	217.0
7	Specific energy consumption	kJ/kg brick	2,035

Table 8: Environment emission

#	Properties	Unit	Value
1	CO	mg/Nm^3	115
2	NO_x(calculated by NO_2)	mg/Nm^3	44.4
3	SO_2	mg/Nm^3	28.8

The kiln is designed, constructed and operated in the environmentally friendly manner. Using sufficient chimney height with water scrubber to handle the dust emission, the kiln is operated with acceptable environmental requirements stated by law. Center for environmental monitoring and protection, Department of Natural Resources and Environment of Phu Tho province, has conducted a report [8] on monitoring the environment impacts of the kiln operation and the result measured in flue gas emission are shown in Table 8. The final conclusion of this report states that the environmental conditions of working labor at the kiln and neighboring people living nearby the kiln are within the acceptable range stated in Law.

4. Conclusion

Work has been done to recognize energy efficiency brick kilns and deeply analyze the energy consumption in a new design of MCBK. With large amount of clay produced worldwide, energy saving for brick making can have a significant contribution on reduction of greenhouse gas emission in brick industry. There are many types of brick kilns today from manual to modernized with different investment costs. Choosing the right technology for brick making will contribute to the development of production and business activities as well as reduce environmental emissions and loss of natural resources of the country.

Energy analysis for the kiln also gives an idea for the new improvement of the kiln design for that brick production could be more efficient with lower heat losses. With sufficient investment cost, MCBK is a promising alternative to the traditional brick kiln and still suitable for the current eco-social condition of developing countries like Vietnam.

Acknowledgments

This work was financially supported by the Ministry of Education and Training under the Grant number B2021 - BKA - 14.

References

[1] E. Gomes, I. Hossain, Transition from traditional brick manufacturing to more sustainable practices, Energy for Sustainable Development, vol. 7, no. 2, Jun. 2003, pp. 66-76. https://doi.org/10.1016/S0973-0826(08)60356-7

[2] İ. Yüksek, S. K. Öztaş, G. Tahtalı, The evaluation of fired clay brick production in terms of energy efficiency: a case study in Turkey, Energy Efficiency, 13, 2020, pp. 1473-1483. https://doi.org/10.1007/s12053-020-09896-y

[3] Kh Mahfuz ud Darain, Mohd Zamin Jumaat, A.B.M. Saiful Islam, M. Obaydullah, Asif Iqbal, Md. Ibrahim Adham & Md. Moshiur Rahman, Energy efficient brick kilns for sustainable environment, Desalination and Water Treatment, Vol. 57, Issue 1, 2016, pp. 105-114. https://doi.org/10.1080/19443994.2015.1012335

[4] S. Prasertsan, T. Theppaya, G. Prateepchaikul and P. Kirirat, Development of an energy-efficient brick kiln, Int. J. Energy Res., 21, 1997, pp. 1363-1383. https://doi.org/10.1002/(SICI)1099-114X(199712)21:15<1363::AID-ER336>3.0.CO;2-9

[5] Rosa-Hilda Chavez, Energy analysis of two coupled brick kilns: an experimental study, Clean Technologies and Environmental Policy, 23, 2021, pp.2235-2249. https://doi.org/10.1007/s10098-021-02130-y

[6] E. Mancuhan, K. Kucukada, Optimization of fuel and air use in a tunnel kiln to produce coal admixed bricks, Applied Thermal Engineering, 26, 2006, pp. 1556-1563 https://doi.org/10.1016/j.applthermaleng.2005.12.002

[7] Xuan-Quang Nguyen *et al*, Research on design and construction of Multi Chambers Brick Kiln for energy saving and environmental protection to produce rough ceramic in Vietnam, Ministry of Education and Training of Vietnam, Vietnam, 2023.

[8] Center for Environmental Monitoring and Protection, Department of Natural Resources and Environment of Phu Tho Province, Environmental Monitoring Report for Brick Manufacturer: Phu Kim An 2, Vietnam, 2022.