ZIGZAG KILNS

A DESIGN MANUAL

CSE

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1. Fixed Chimney Bull's Trench Kiln

In South Asia, the most widely used technology for firing bricks is the Fixed Chimney Bull's Trench Kiln (FCBTK). It involves a continuous, moving fire kiln in which the fire is always burning and moving forward in the direction of air flow, due to the draught provided by a chimney. The bricks are warmed, fired and cooled simultaneously in different parts of the kiln.

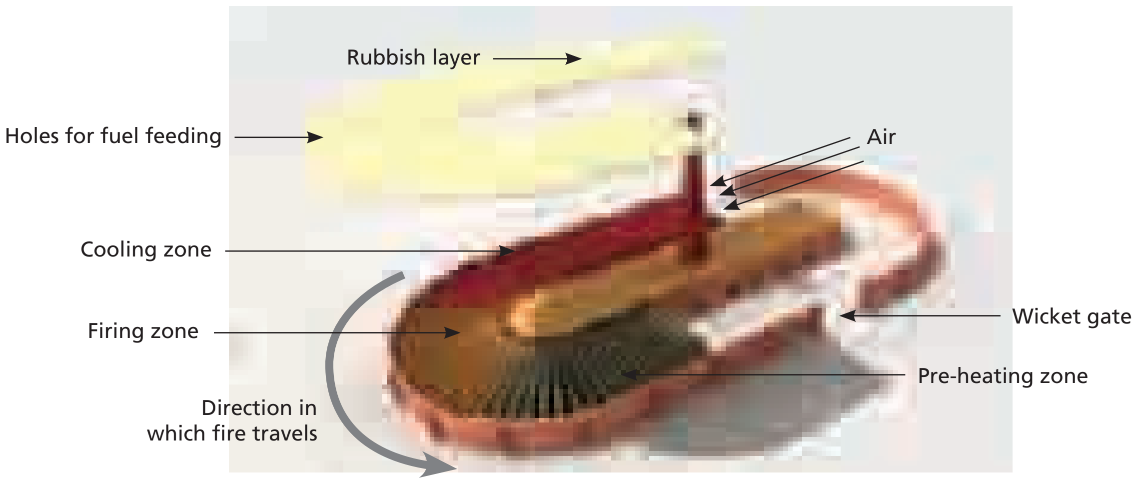
There are basically two types of FCBTKs in operation: Forced or induced draught and natural draught. In forced or induced draught, a fan is provided to create the draught from the chimney, whereas in natural draught, the chimney itself creates the required draught.

PROBLEMS WITH FCBTK TECHNOLOGY

In FCBTKs, air travels in a straight line and remains in the kiln for a shorter duration as the combustion zone is smaller. Therefore, the air does not get sufficient amount of time to properly mix with the fuel, resulting in incomplete combustion. This decreases the overall efficiency of the kiln.

Improper distribution of heat in different parts of the combustion zone is another major downside of an FCBTK. Green bricks stacked for firing are not exposed to a uniform temperature and only 60 per cent of the bricks fired turn out to be Class I (good quality).

Figure 1: Schematic illustration of operations and firing zones of an FCBTK

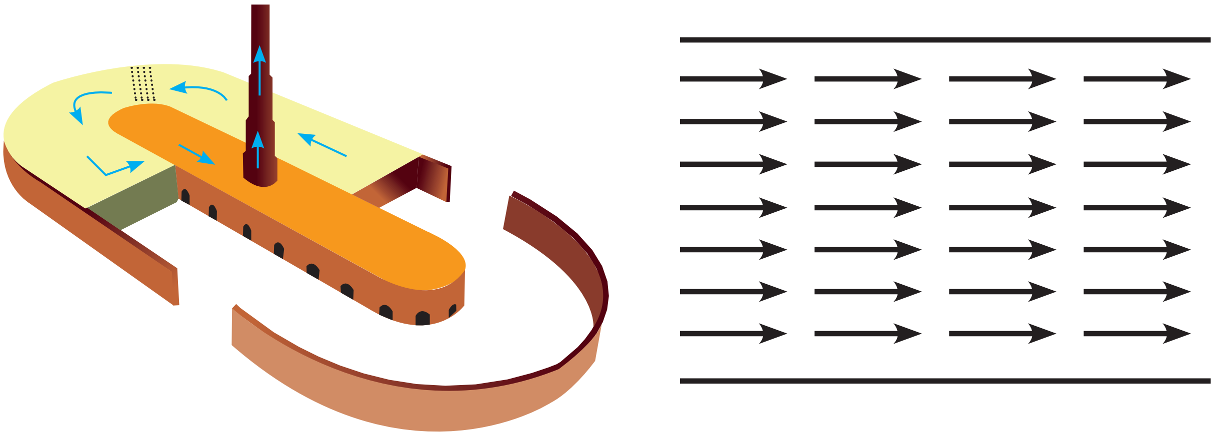


Source: Screen grab from https://www.youtube.com/watch?v=E_8zCKv7KHs

2. Zigzag kilns

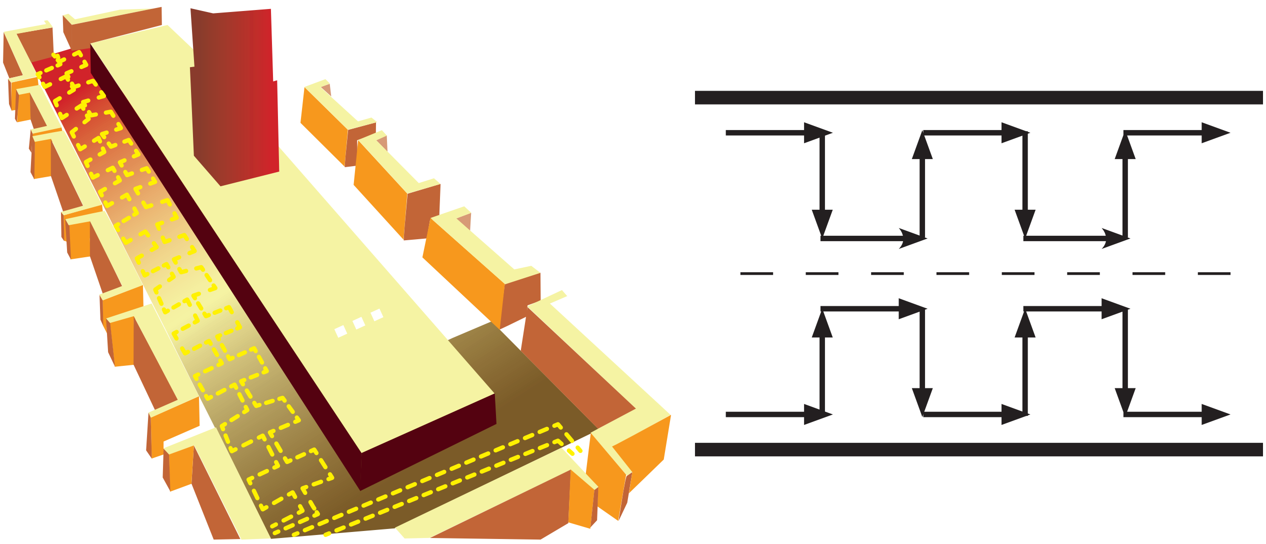
In zigzag kilns, green bricks are arranged in a way that forces hot air to travel in a zigzag path. The length of the zigzag air path is about three times that of a straight line air path, and this improves the heat transfer from the flue gases to the bricks, making the entire operation more efficient.

Figure 2: Straight line firing



Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

Figure 3: Zigzag firing



Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

Table 1: Techno-economics of retrofitting an FCBTK into zigzag brick kilns

	Initial FCBTK	Retrofitted zigzag
Annual production	40 lakh	40 lakh
Coal consumption per lakh bricks	16 tonne	12 tonne
Class I bricks produced (percentage)	55–60	80–90 per cent

	Induced zigzag	Natural zigzag
BREAK UP OF THE COST		
Labour cost	Rs 5.5–7.5 lakh	Rs 5.5–7.5 lakh
Material (other than brick)	Rs 1–1.5 lakh	Rs 1–1.5 lakh
Equipment	Rs 2–2.5 lakh	Rs 2–2.5 lakh
Fan (with engine)	Rs 3–4 lakh	Not applicable
Chimney	Not applicable (same chimney can be used)	Rs 8–10 lakh
Bricks @ Rs 3/brick	Rs 6–9 lakh (for additional 2–3 lakh bricks)	Rs 9–12 lakh (for additional 3–4 lakh bricks)
Total	Rs 17.5–24.5 lakh	Rs 25.5–38.5 lakh
RETROFITTING BENEFITS		
Annual coal savings 160 tonne @ Rs 10,000 per tonne	Rs 16 lakh	Rs 16 lakh
Increase in revenue due to higher number good quality bricks (considering 8 lakh additional Class-I bricks annually) @ Rs 1 per brick	Rs 8 lakh	Rs 8 lakh
Annual expenditure on operation and maintenance of fan	Rs 2.5 lakh	
Total annual savings	Rs (16 + 8 - 2.5) = 21.5 lakh	Rs (16 + 8) = 24 lakh
Simple payback period	One brick season	One–two brick seasons

Source: CSE analysis

The zigzag path also ensures a more uniform distribution of heat and this increases the number of Class I bricks to about 90 per cent. Emissions from the kiln are also reduced considerably.

FCBTKS VS ZIGZAG KILNS

Obviously, shifting from FCBTK to zigzag technology is an attractive option in terms of energy consumed and emissions reduced. But how do other costs and benefits pan out?

The total cost incurred in retrofitting an FCBTK into a zigzag kiln ranges from Rs 17.5–38.5 lakh (and depends on the size and condition of the kiln). *Table 1: Techno-economics of retrofitting an FCBTK into zigzag brick kilns* presents an overview of the gains and costs to be made from the transition. It is clear that the costs incurred can be recovered within a year.

In case of natural draft zigzag kilns, the same chimney can be used if the daily production is upto 30,000 bricks. However, since we are using a daily production of 44,000 bricks in our calculations, the chimney needs to be rebuilt. This translates into an additional cost of Rs 8–10 lakh and does not require any external source to create draught, thereby not putting any extra burden on operational costs.

In induced draft zigzag kiln, erratic power supply sometimes necessitates the use of an external power source to run the fan. This requires around 1.5 litres of diesel per hour. The average daily cost of diesel come to around Rs 2,160 (considering the diesel price of Rs 60 per litre). The operation and maintenance cost of the fan and the DG set is over and above this.

The savings on diesel and operation and maintenance cost per kiln during a single brick season would be around Rs 250,000, thus the cost incurred in making new chimneys will be recovered in four season.

TIMELINE FOR RETROFITTING

In this section, we will discuss the time required for retrofitting of a kiln. A few assumptions have been made in order to generalize the process, these are:

Figure 4: Timeline of conversion to a natural draft kiln

NATURAL DRAFT KILNS

For retrofitting an FCBTK and converting it into a natural draft kiln, the chimney needs to be rebuild and for that the older chimney needs to be dismantled. For dismantling the older chimney, the kiln owners have two options

To carry out the dismantling in such a way that they can extract the maximum number of bricks from the older chimney. This method is time-consuming and requires 10–15 days

To cut the chimney at the base and let it fall like a tree. This saves time (takes only about 3 days) but reduces the number of bricks that can be recovered

After this, construction on the new chimney starts and takes around 30 days

For the safety of the workers, the rest of the work begins only once the chimney is completed

The rest of the process is similar to that of retrofitting an FCBTK and converting it into an induced draft brick kiln; the only difference is that natural draft kilns do not need to be equipped with a fan

The entire process takes around 80–90 days, after which stacking and firing can commence

Source: CSE

Figure 5: Timeline of conversion to an induced draft kiln

INDUCED DRAFT KILNS

↓

It is a common practice to dismantle one side of the outer wall first for the smooth entry and exit of men and machines

↓

The miyan is dismantled and both teams help clear the area. The process of dismantling usually takes around 10–15 days

↓ ↓

In the next 20–25 days, the miyan structure with the main and side nali is completed by one team	The other team works on the outer wall

↓ ↓

Clay filling in the miyan and outer walls takes place simultaneously

↓

Only a small section of the outer wall is left open for another five days to clear the insides of the kiln and give the clay filling of the miyan time to settle

↓

After five days, the final finishing to the miyan wall and the clay insulation is completed

↓

The process of finishing the outer wall takes another five days

↓

Finally, kiln floor is finished and the fan is fitted. These processes take five days and can be done simultaneously

↓

The complete process of retrofitting takes around 50–60 days, after which the kiln is ready for stacking and firing the next batch

Source: CSE

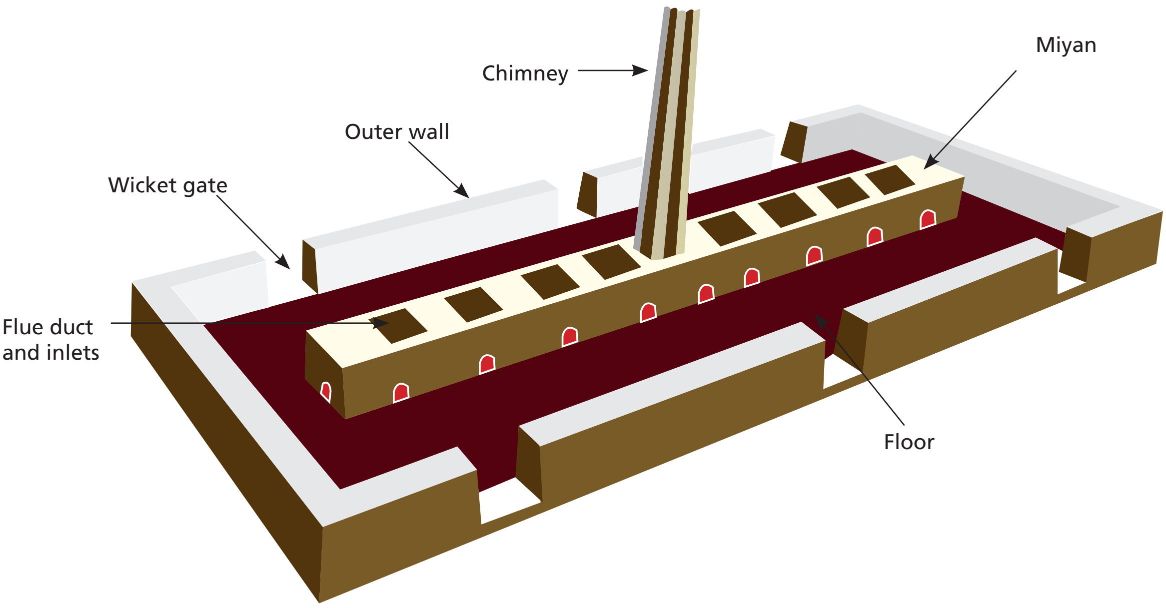
- The kiln is empty and no bricks are stacked inside it.
- Two groups, each consisting of 15 labourers, is working together on retrofitting the kiln. One group is working on the miyan and the duct system, and the other on the outer walls of the kiln.
- Dismantling work is carried out with help of machinery.
- For induced draft, the chimney remains unchanged, but a new one is built for a natural draft.
- The ducting system with the miyan wall and the outer wall are rebuilt.
- Clay filling between the wall and the miyan will be done simultaneously

3. Anatomy of a kiln

The construction of kilns is a complex interplay of several factors, including basic building principles, and considerations of thermodynamics and aerodynamics. The key components which, if properly constructed, can ensure energy efficiency and emission reduction in a kiln are as follows:

- Kiln dimensions
- Flue duct and inlets
- Kiln wall structure
- Wicket gate
- Chimney
- Floor

Figure 6: Anatomy of a typical kiln



Source: *Design Manual Improved Fixed Chimney Brick kiln, MinErgy, 2015*

4. Kiln design

The production capacity of a kiln and size of the bricks produced are the two most important factors determining the design of the kiln. In the Delhi NCR region, the brick size is generally 9 x 4.5 x 3 inches.

For the same trench width, about 10,000 more bricks can be fired per day in an induced draught kiln as compared to natural draught zigzag kiln, because the brick setting is denser.

In this section, we have taken an example of a kiln with production capacity of 44,000 bricks per day for natural draft and 55,000 bricks per day for induced draft. The dimension of the other components of the kiln and the brick setting is explained keeping this mind.

DUG WIDTH

Dug width is defined by brick dimensions and the required daily production. There are two methods which can be followed to define dug width:

- Dug width defined by brick dimensions and brick stack length
- Fixing the dug width and adjusting the brick stack pattern accordingly

Since brick size varies from kiln to kiln, in order to generalize the design, the second methodology is followed. Table 2: Dimensions of typical natural draft zigzag kiln can be used to decide the trench width as per the production capacity of the kiln.

In an induced draft kiln, the chimney height remains constant at around 90 feet. The trench

Table 2: Dimensions of a typical natural draft zigzag kiln

Bricks/day	Trench/dug width	Chimney height	ID bottom*	ID top*	Height of main nali	Width of main nali	Gali size
21,000	18 ft	120 ft	9 ft x 9 ft	3 ft x 3 ft	4ft	2.5ft	9 ft
25,000	22 ft	135 ft	9 ft 6 in x 9 ft 6 in	3 ft 2 in x 3 ft 2 in	4ft	2.5ft	11 ft
30,000	23 ft 6 in	135 ft	9 ft 6 in x 9 ft 6 in	3 ft 2 in x 3 ft 2 in	4ft	2.5ft	11 ft 9 in
36,000	26 ft	135 ft	10 ft x 10 ft	3 ft 4 in x 3 ft 4 in	4.5ft	2.5ft	13 ft
39,000	28 ft	140 ft	10 ft 6 in x 10 ft 6 in	3 ft 6 in x 3 ft 6 in	4.5ft	2.5ft	14 ft
41,000	31 ft	140 ft	10 ft 6 in x 10 ft 6 in	3 ft 6 in x 3 ft 6i n	4.5ft	2.5ft	15ft
44,000	33 ft	145 ft	12 ft x 12 ft	4 ft x 4 ft	5 ft	2.5 ft	16 ft 6 in
48,000	35 ft	145 ft	12 ft x 12 ft	4 ft x 4ft	5 ft	2.5 ft	16 ft 6 in
52,000	37 ft	145 ft	12 ft x 12 ft	4ft x 4ft	5 ft	2.5 ft	16 ft 6 in
58,000	39 ft	150 ft	13 ft x 13 ft	4 ft 4 in x 4 ft 4 in	5 ft	2.5 ft	16 ft 6 in

*Note: *Chimney ID (top and bottom) are provided for a square chimney*
Source: Prepared by CSE

width can be adjusted by adding 10,000 to the column of number of bricks per day in the *Table 2: Dimensions of a typical natural draft zigzag kiln.*

DUG WALL HEIGHT

The dug wall or miyan wall height is the height measured from the dug surface. It is generally 10–11 feet.

CHAMBER LENGTH

In general, the length of the chamber varies from six to nine feet. Better zigzagging of the air flow can be achieved by decreasing the length of the chamber. Therefore, six feet long chambers are recommended for both induced and natural draft zigzag kilns.

SIDE NALI SPACING

Side nalis are flue inlets placed at regular intervals along the length of the miyan. The spacing is defined by the length of the chamber. In case of a six feet long chamber, the side nali is placed at the center of every third chamber, i.e., the spacing is 18 feet from center to center. The spacing remains the same for induced and natural draft zigzag kilns.

GALI WIDTH

The gali is a narrow section on either edge of a zigzag kiln, always narrower in width than the dug width. To optimize the kiln design, the gali width will be taken as half of the dug width and will be same for induced and natural draft zigzag kilns.

MIYAN DIMENSION

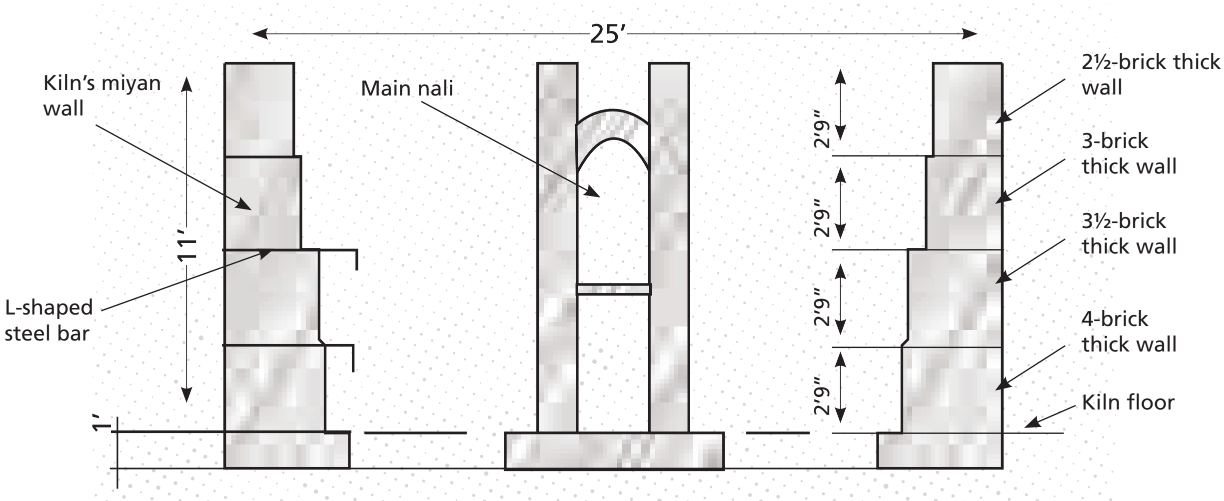
The chimney of the kiln is situated at the centre of the miyan. The length of the miyan is decided according to the number of chambers to be set on one side of the trench length. For a smaller kiln of 26 chambers, i.e., the miyan length should be 156ft (26 ft x 6ft chamber = 156ft). If a kiln has 32 chambers, miyan length should be 192ft (32 ft x 6ft chamber = 192ft).In case the chimney is located at the center of the miyan, the width of the miyan should be able to accommodate the base of the chimney. In such cases, the width of the miyan usually varies between 18 to 30 feet. If, on the other hand, the chimney is located on one side of the kiln, the width of the miyan can be less (sufficient enough to accommodate the flue duct system)—about 16–18 feet. In a natural draft zigzag design, a miyan with a width of 25 feet is sufficient to accommodate the chimney foundation; in an induced draft zigzag kiln, a miyan width of 18 feet is recommended.

Dimension of a miyan;

- Miyan length = 156 feet (26 chambers) or 192ft (32 chambers)
- Miyan width = 25–28 feet for natural and 18 ft for induced draft zigzag kilns
- Miyan height = 10–11 feet

To construct the miyan wall, the ground is dug one foot deep to give the wall structural stability. Plastering of the wall is done with a homogeneous clay mixture. A three inch inclination is maintained from the bottom to the top of the miyan wall towards the main nali to provide additional structural stability to the wall. Six feet long L-shaped steel is recommended after the first four-brick-thick wall and the second 3.5-brick-thick wall (see *Figure 7: Schematic of a miyan wall*).

Figure 7: Schematic of miyan wall



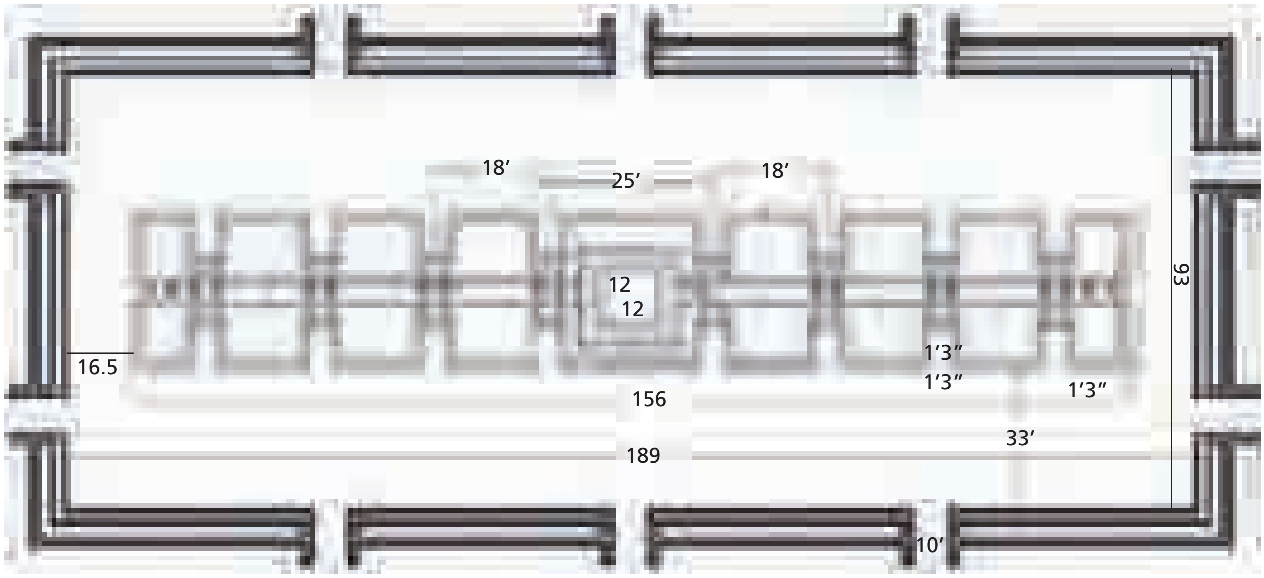
Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

KILN'S OUTER DIMENSIONS

A kiln's outer dimensions can be calculated simply by adding dug width and gali width to the miyan wall's dimensions.

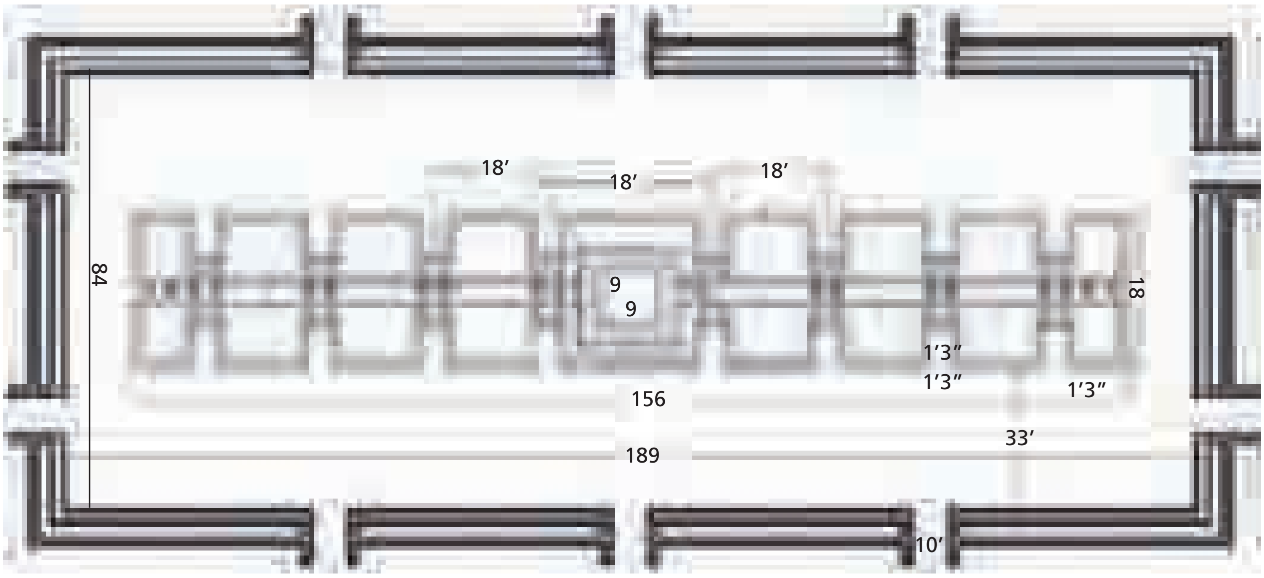
Length of kiln (excluding outer wall thickness) = Length of miyan + 2 x gali width
= 156 + 2x16.5 = 189 ft (for both natural and induced draft zigzag kilns with 26 chambers)
Breadth of kiln (excluding outer wall thickness) = Width of miyan + 2 x dug width
= 18 + 2x33
= 84 feet (for an induced draft zigzag kiln)
= 25 + 2x33
= 93 feet (for a natural draft zigzag kiln)

Figure 8: Natural draft zigzag kiln



Source: CSE

Figure 9: Induced draft zigzag kiln



Source: CSE, 2017

FLUE DUCT SYSTEM

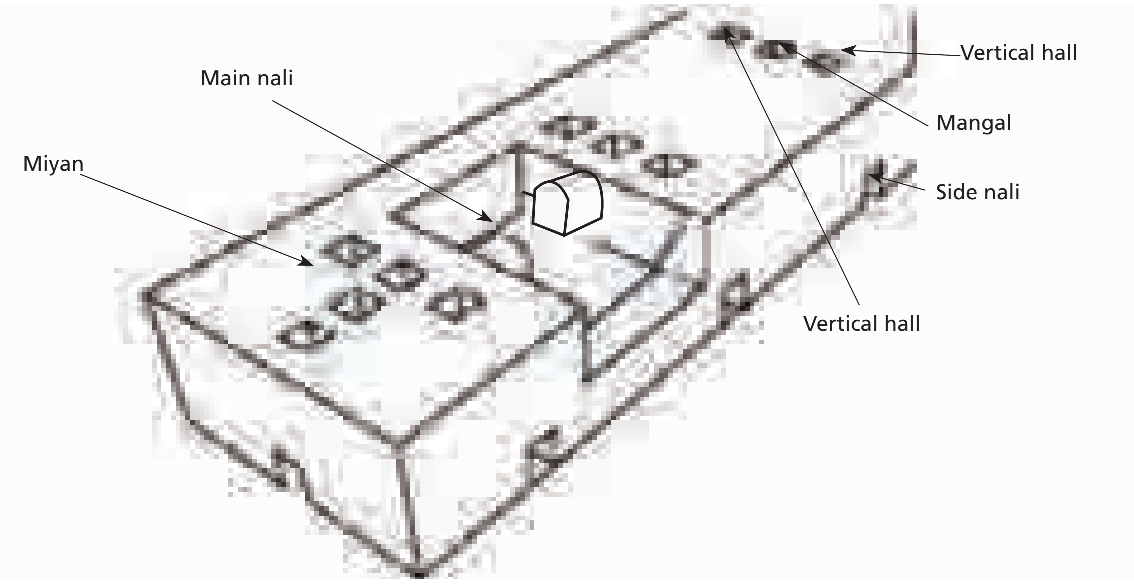
The flue duct system consists of designing the size and dimensions of following components:

- Main nali (main flue gas inlet)
- Side nali (side flue gas inlet)
- Vertical hall or mangal

Main nali

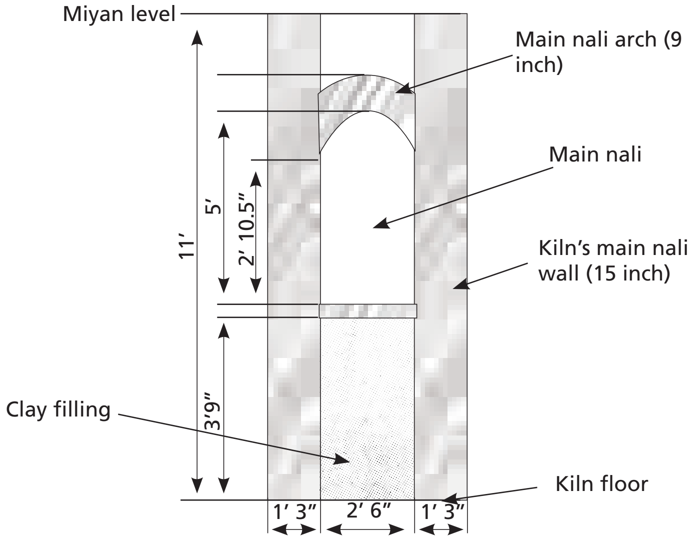
The main nali is either circular or rectangular and runs the length of the miyan.The main nali is located four feet above the floor of the kiln. The width of the main nali is about two

Figure 10: Systematic diagram of flue duct system



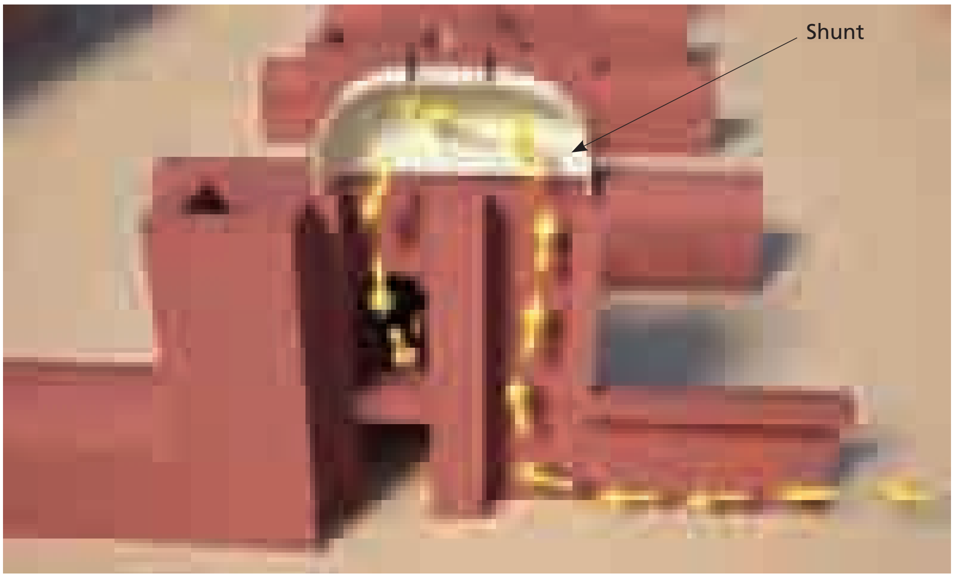
Source: *Design Manual Improved Fixed Chimney Brick kiln,* MinErgy, 2015

Figure 11: Schematic design of a main nali



Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

Figure 12: Illustration of a shunt connected to the main and side nalis



Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

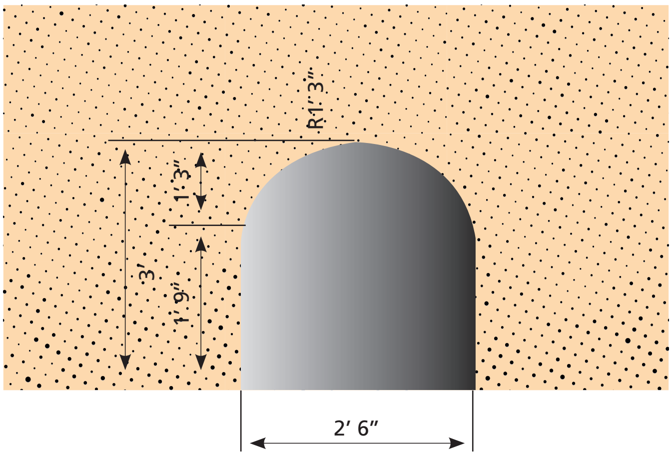
feet three inches. Its walls can be constructed with Class III bricks but the arch should be made only with Class I bricks.

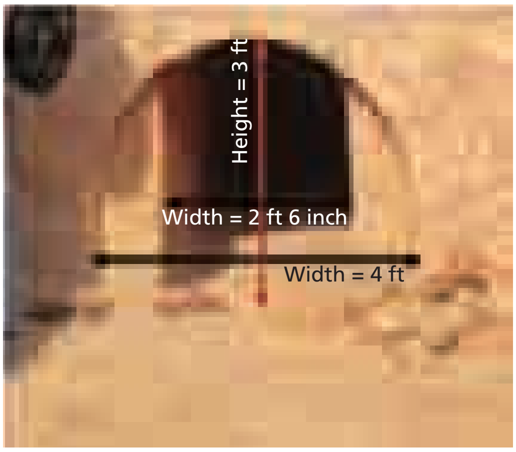
A pressure loss or drop occurs when friction due to roughness of surface, duct divergences and bends acts on the gases as they flow through the duct system. This pressure drop is always taken into consideration.

Side nali

The cross-section of a side nali is only about 70 per cent of the mail nali, because soot deposition is considerably lower in the former.

Figure 13: **Schematic design of the side nali**





Source: *(Left) Design Manual Improved Fixed Chimney Brick kiln, MinErgy, 2015, (right) Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

Area required for the flue inlet = 70 per cent
Assumed inlet width = 2.5 ft, based on which the height of the side nail can be calculated to be three ft.

Vertical hall or mangal
Vertical hall is a rectangular structure that serves as connector between the main and side nalisand the shunt. The size of the opening of the vertical hall should be almost equal to the cross-section of the side nali (less than that of the main nali).

Hence, in reference to above calculation on a side nali, the cross-sectional area of the vertical hall is 2.5 ft x 2.5 ft= 6.25 ft^2.

Figure 14: **A vertical hall is situated on top of the miyan**

Source: *Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation,* Greentech Knowledge Solution Pvt Ltd, 2016

KILN WALLS

The outer wall and the miyan wall are the two key kiln walls. Since there is a lot of workers' movement around the walls, they need to be strong and durable.

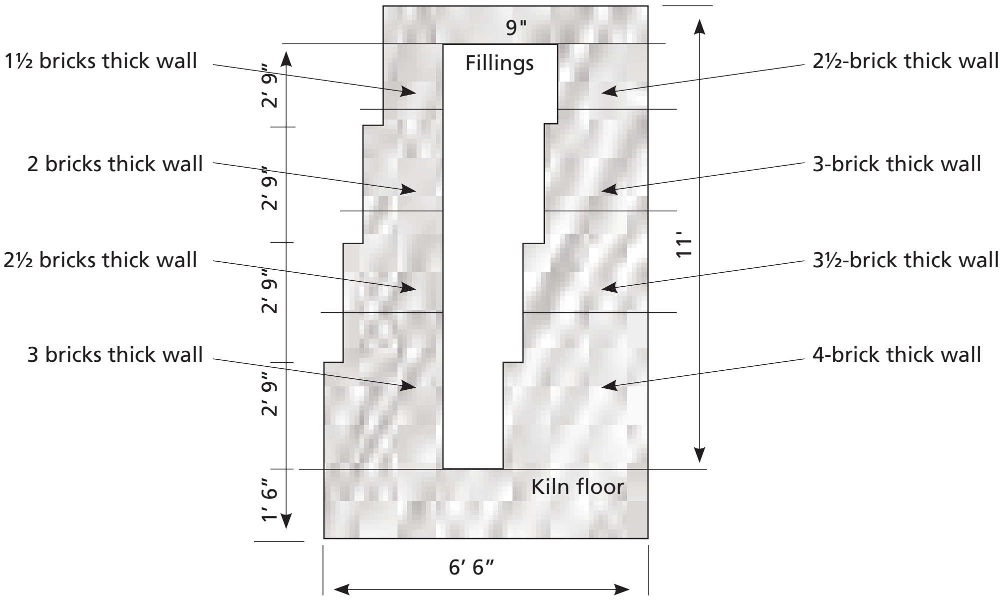
Outer wall design

Generally, the outer wall is a double brick wall plastered with mud. The space between the walls is filled with mud and ash, for insulation. A three inch inclination is maintained from the bottom to the top of the outer on the outside of the kiln.

Expansion joints

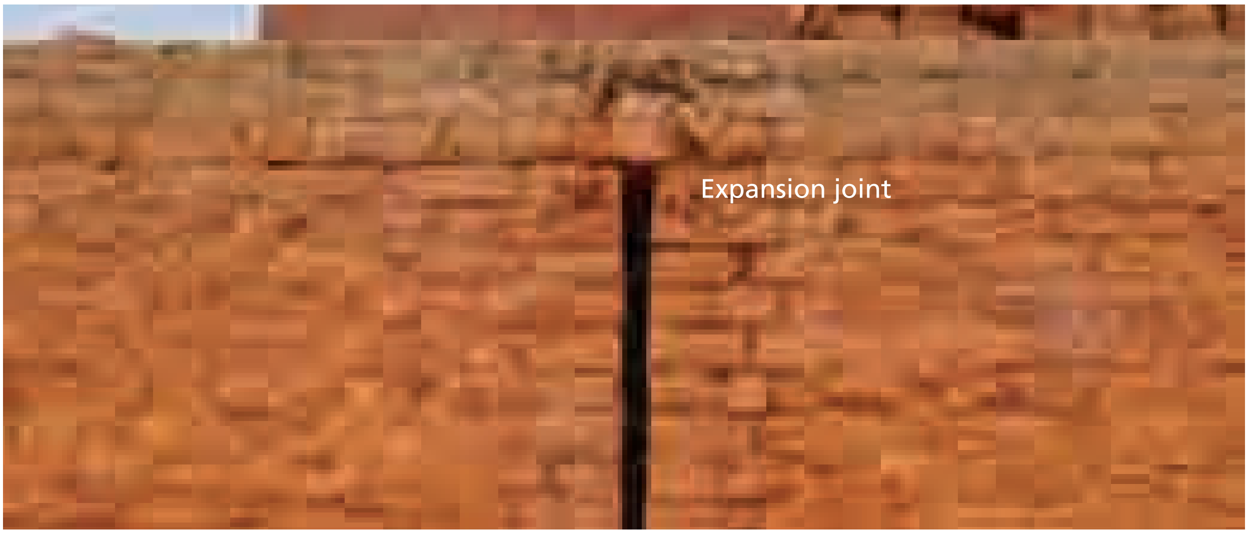
Expansion joints are provided in the walls facing the trench of the kiln (i.e inside of the outer kiln walls and outside the miyan wall). One expansion joints is provided between two wicket gates on the kiln's outer wall and between two side nalis of the miyan wall facing the trench as shown in *Figure 16: Expansion joints*. The expansion joints are two inches wide and 18 inches deep, and start from three feet nine inches above the kiln floor, and have a total height of five feet three inches.

Figure 15: Cross-section of the outer wall



Source: Design Manual Improved Fixed Chimney Brick kiln, MinErgy, 2015

Figure 16: Expansion joints



Source: CSE, 2016

Heat loss from the outer wall

The temperature inside a kiln is higher compared to the ambient temperature and because of this heat loss from the walls is a major concern. About 35 per cent of the total heat is lost through the kiln surfaces, 15 per cent from the top and the rest from the sides and the bottom.

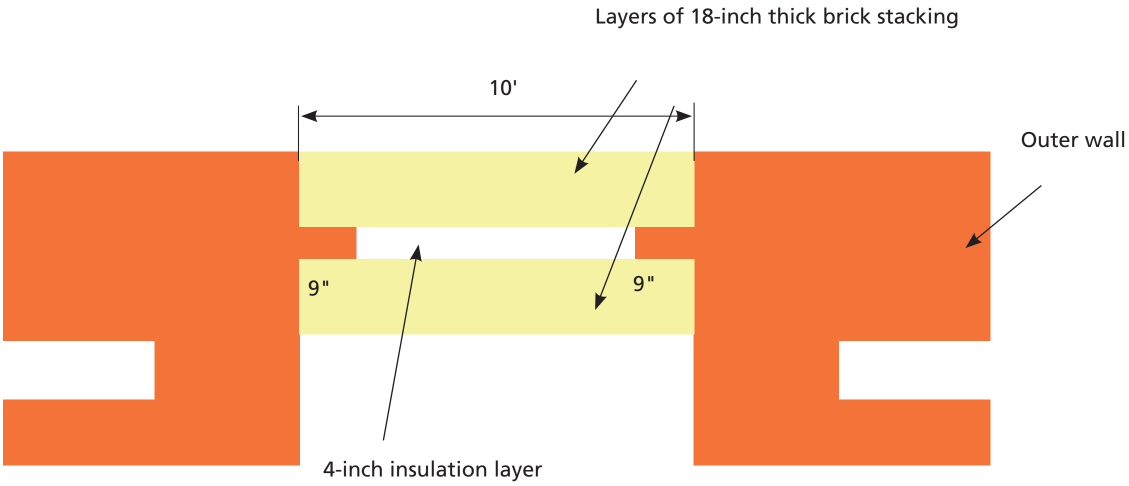
The heat loss depends on the wall thickness. The thicker the wall, the less the heat lost. An analysis of Nepal brick kilns done by MinErgy in 2015 is given in *Table 3: Saving coal by imporved insulation from different wall designs*. Brick owners can save around Rs 2,000 a day by ensuring better insulation.

Table 3: Saving on coal by improved insulation from different wall designs

	18 inch thick wall	5 feet thick wall
Production capacity (bricks/day)	70,000	70,000
Total heat loss through the kiln walls (MJ/day)	7,533	2,508
Equivalent amount of coal (CV = 5,500 kcal/kg) being wasted as heat loss from kiln walls (in kg/day)	327.7	109.1
Cost of the coal equivalent heat being wasted through the kiln walls (coal @ Rs 10/kg)	3,277	1,091
Total savings (in Rs/day)	3,277–1,091 = 2,186	

Source: Design Manual Improved Fixed Chimney Brick kiln, MinErgy, 2015

Figure 17: Wicket gate



Source: CSE, 2017

WICKET GATE OR DWARI

Wicket gates are provided in the outer wall of the kiln for transportation of bricks in and out of the kiln. There is no consistent design methodology to define size, positioning and number of wicket gates (dwaris) in zigzag kilns. The width of the wicket gates should be sufficient for loaded vehicles to move in and out of the kiln. Smaller and fewer wicker gates reduce heat loss from the kiln.

The following considerations must be taken into account while designing a wicker gate:

- Heat loss must be minimized
- It should be easy to transport green bricks into and fired bricks out of the kiln
- It should be easy and to transport green bricks into the dug efficiently using any mode of transport, either human, animal, electric cars or trucks

We propose a total of six wicket gates (three on either side) for a 11-feet-long outer wall. No wicket gates have been proposed in the gali area.

The common practice is to close wicket gates with a two-brick-thick (18 inch) wall with mud plaster. Heat loss and air leakage from such constructions is significant. Therefore, some progressive kiln owners construct two 18 inch brick walls with a four inch gap in the middle filled with ash, for better insulation. This is also our recommendation.

KILN FLOOR

Heat loss through the floor varies with the type of soil, moisture content and water table. Generally, it is between 10–20 per cent of the total heat input. Therefore, better material and design for the floor can make a kiln more energy efficient.

Figure 18: Kiln floor design

Source: Design Manual Improved Fixed Chimney Brick kiln, MinErgy, 2015

Recommended kiln floor design

The recommended floor design has a layer of sand, aluminum sheets, and layers of soling brick (see *Figure 18: Kiln floor design*).

CHIMNEY

The chimney is the most important and costly section of a kiln structure. Hence, chimney design is of prime concern for all kiln owners.

Natural draft

In natural draft brick kilns, the temperature difference between the air inside and outside the kiln creates a draft inside the kiln, which is crucial in the processes of thermodynamics and aerodynamics of the kiln. The production capacity of a kiln depends on the chimney height. For a daily production of 44,000 bricks, a chimney height of 145 feet is recommended.

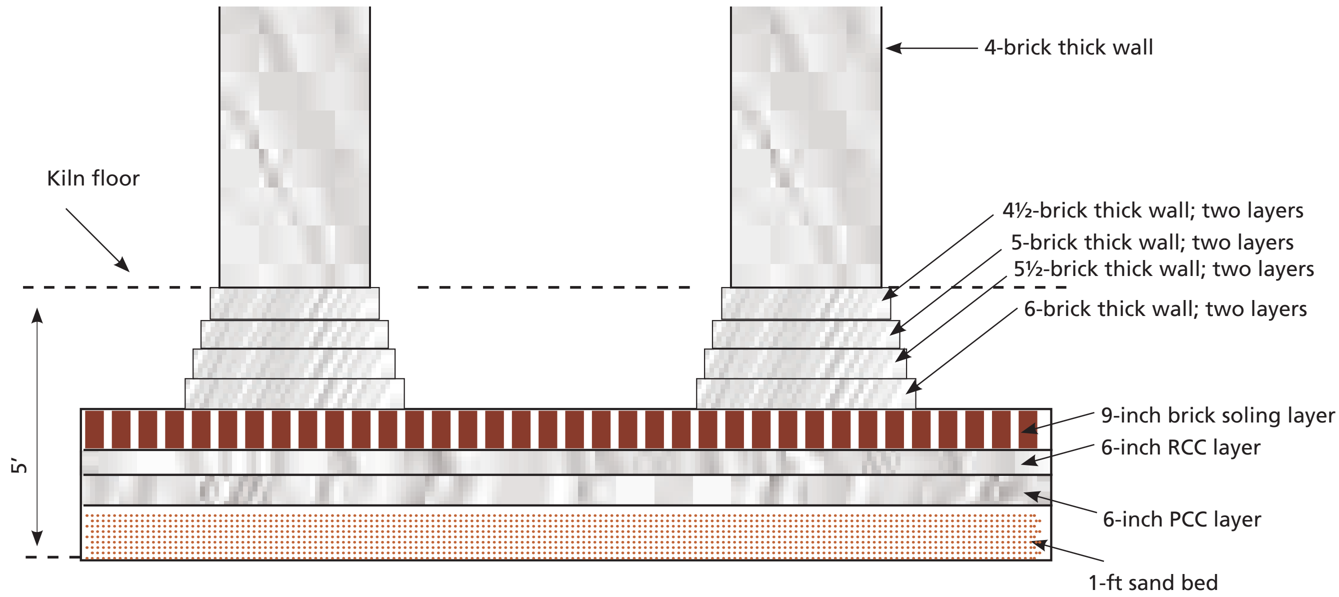
A square chimney is faster to construct, and therefore, we have described the construction of a 145-feet-high square chimney in this section.

Base of the chimney

The cross-section at the bottom of the chimney will be 12 x 12 feet and at the top it will be 4 x 4 feet. The foundation of a square chimney should be as shown in *Figure 20: Schematic diagram of a chimney base.*

The foundation will be 22 feet x 22 feet and five feet deep below the kiln floor. Six inch layers one each of PCC and RCC, over a one feet layer of sand, are provided to furnish structural stability. The first 50 feet of the chimney must be built of Class I bricks, beyond that Class II bricks can be used. The inner wall of the chimney will be plastered with a clay mixture. Lighting arresters should be provided

Figure 19: Schematic diagram of a chimney base



Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

The wall of the chimney should be made of Class I bricks upto a height of 50 feet, beyond that Class II bricks can be used. The inner wall of the chimney is plastered with clay mixture. A lightening arrester should be provided in the chimney with a proper earthing strip.

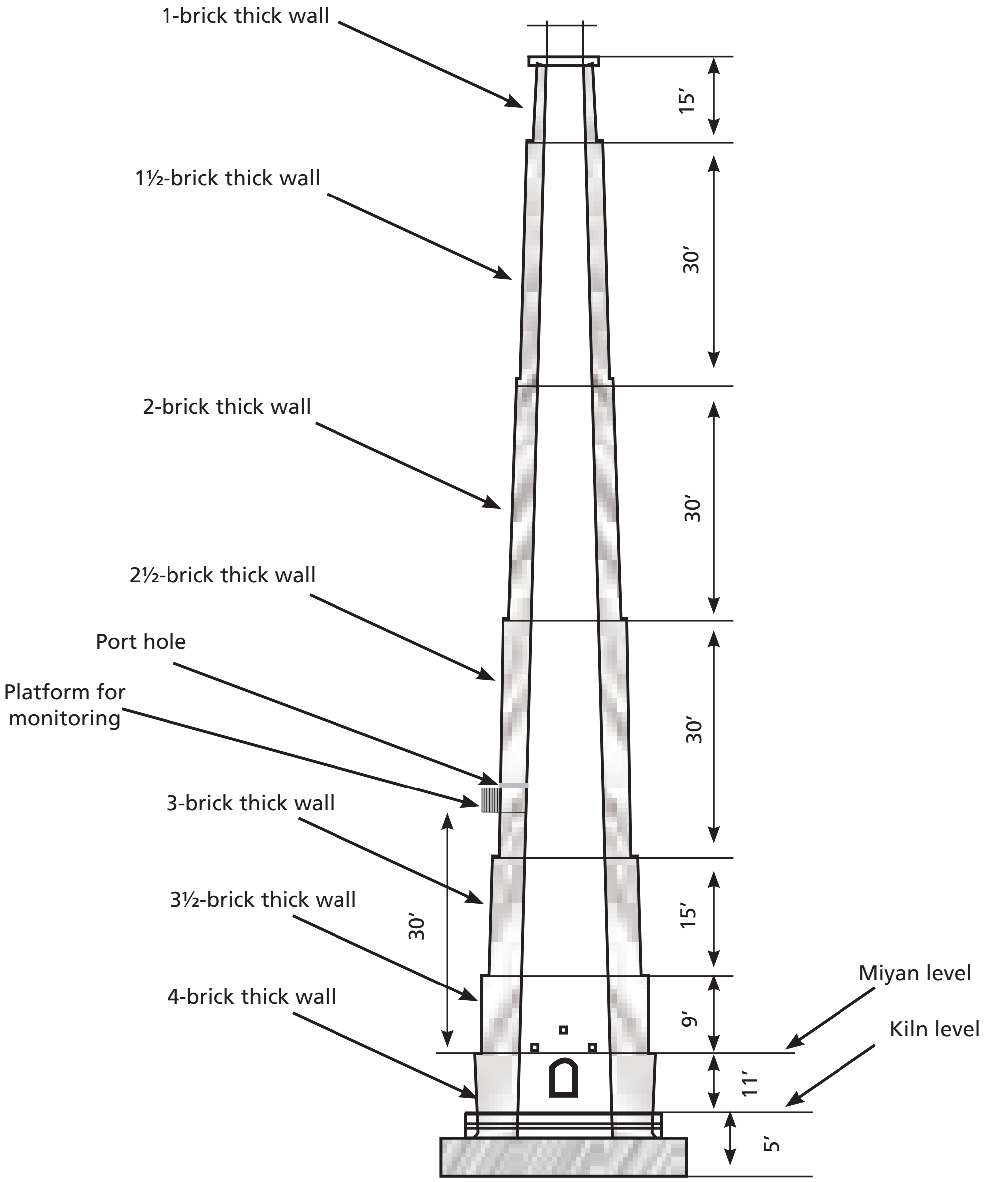
For stack monitoring, a port hole and a proper platform for placing the monitoring instrument should be provided. The platform should be three feet six inches below the port hole. The port hole should be placed 40 feet from the miyan of the kiln.

Induced draft

The location of the chimney varies from one induced draft kiln to another. Sometimes the chimney is located at the middle of the miyan,at other times it is placed on one side of the kiln.

Chimney height for an induced draft kiln has been calculated using an empirical formula recommended by the Central Pollution Control Board (CUPS/ 13/1984–85), which is based on the dispersion of sulphur dioxide (SO_2) and particulate matter (PM) emissions so that their concentration in the air falls below the required limits. The more the height of the chimney, the more dispersion of emissions. A minimum height of 27m (approximately 90 feet) has been mandated by MoEF&CC for brick kilns in its new draft standards.

Figure 20: Section design of a 145 feet natural draft kiln



Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

The formula is as follows:

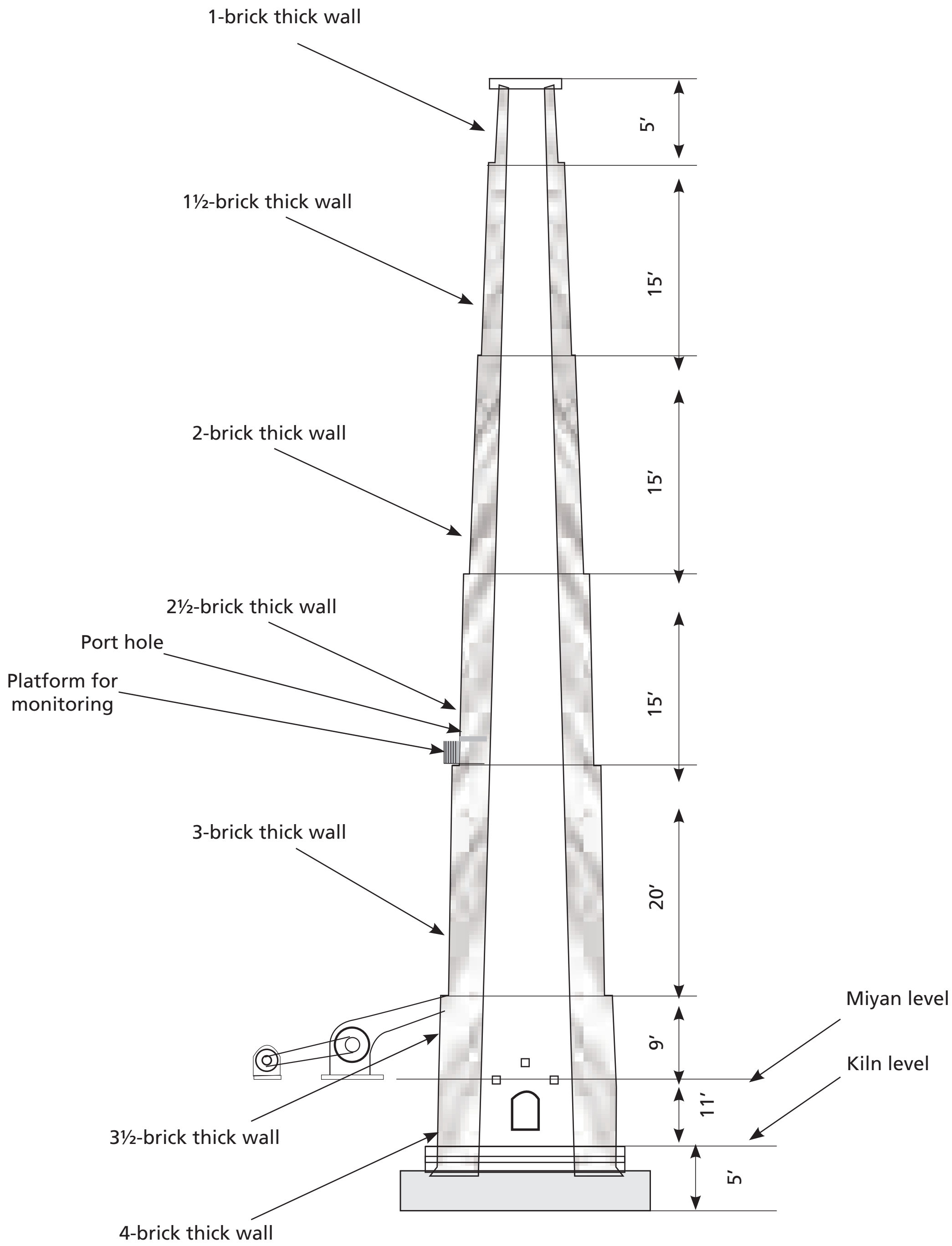
- H = 14 (Q)0.3 (where Q is sulphur emission rates in kg/hr)
- H = 74 (Q)0.27 (where Q is PM emission rates in tonne/hr)

This comes out to be less than 27 m so the higher mandated value, which is 27 m (approximately 90 feet) is recommended here.

Fan

In an induced draft kiln, the draft is created with the help of a fan. The capacity of the fan depends on the trench width and the number of bricks to be produced per day. For a daily production of 55,000 bricks and a trench width of 33 feet, a 15 horsepower fan is generally used. The fan's discharge section is connected to the chimney.

Figure 21: Section design of a 90 feet induced draft kiln



Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

5. Apparatus used in a kiln

SHUNT

A shunt is a tubular connector which is used to connect the flue hole to the central hole located parallel to it. Underneath, it is connected to the chimney through a connector passage. The main benefit of using a shunt is that it helps in preventing air leakages through the flue ducts.

SHUNT METER

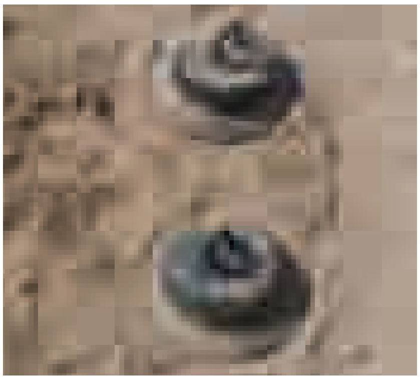
A shunt meter is a temperature measuring device with a metal rod attached to it. The rod is inserted into a hole made on the top of a shunt, and it measures the temperature of the flue gases flowing from the kiln to the chimney via the shunt.

COAL BUCKET

It is a simple low-height drum, circular or square, placed appropriately over the holes through which fuel is fed,to give the person feeding fuel easy access, as the feeding process is almost continuous.

TAWA

A tawa is an elliptical iron sheet used to cover the holes through which fuel is fed. The name comes from its resemblance with the tawa used to make rotis in households across South Asia. It is lifted used a hooked iron rod because it is too hot to touch directly. Earlier, these tawas were made with simple iron sheets, but nowadays insulated tawas have been introduced to prevent heat loss from the kiln.



THERMOCOUPLE

A thermocouple, known more commonly as a temperature meter, is an electronic device with a metal rod or probe which is inserted into the kiln through the fuel feeding hole. Nowadays, a gun-shaped laser thermocouple is also available which directs a laser beam into the kiln and displays the temperature of the surface hit by the laser beam.

Probe of a thermocouple

Meter of a thermocouple

6. Operational aspects

BRICK SETTING

In both natural and induced draft zigzag kilns, the setting of green bricks is done in chambers. In natural draft kilns, depending upon the width of the trench, bricks can be stacked to achieve single, double or triple zigzag patterns. In induced draft kilns, bricks are mostly stacked in a denser single zigzag pattern. In the gali, bricks are set in a straight line, as in an FCBTK kiln.

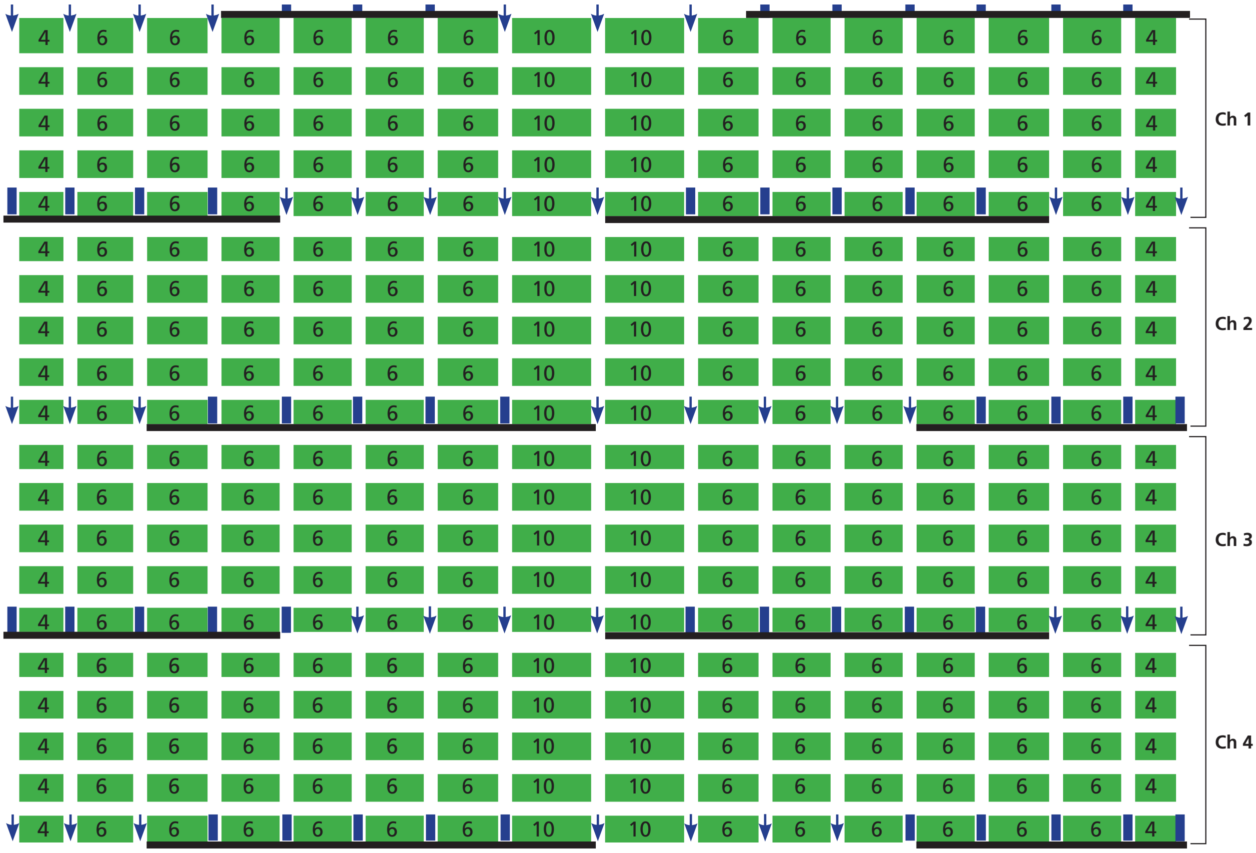
Figure 22: Brick setting in chambers in a natural zigzag Kiln

Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

In a natural draft zigzag kiln, bricks are set in five lines in each chamber. A gap of five inches is maintained between adjacent lines for flow of air. The width of a column of green bricks caries with the width of the trench and the production capacity of the kiln. For a trench width of 33 feet and a daily brick production of 44,000 bricks (and triple zigzag pattern), two columns of four bricks, two columns of 10 bricks, and 12 columns of six bricks are recommended.

In induced draft brick kilns, the size of each chamber is around six feet. Bricks are set in six lines in each chamber; the length of each line is equal to the length of a brick. A three inch gap is maintained between adjacent lines to help air flow. Green bricks are stacked in columns, the width of which depends on the width of the trench and production capacity. For a trench width of 33 feet and a daily brick production of 55,000, two columns of four bricks, four columns of six bricks, and 10 columns of seven bricks is recommended.

Figure 23: Top view of sixteen-column green brick setting in a typical triple zigzag natural draft kiln

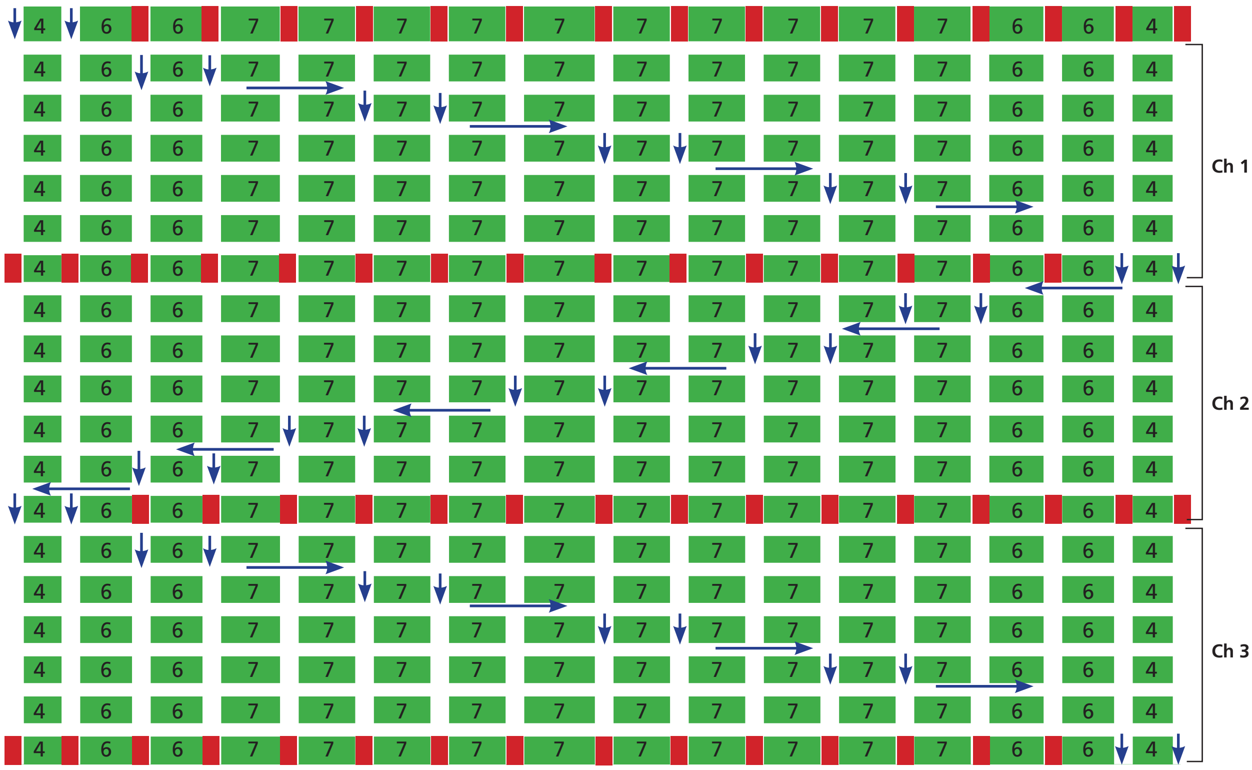


Source: CSE, 2017

Figure 24: Brick setting in chambers in an induced zigzag kiln

Source: CSE, 2017

Figure 25: Top view of a sixteen-column green brick setting in a typical induced draft kiln.



Source: CSE, 2017

FUEL FEEDING

Fuel feeding in both natural and induced draft kilns is done for six chambers at a time. Ideally, different kinds of fuel should be used in each chamber according to the temperature with a particular chamber (see *Table 4: Type of fuel to be fed in different chambers*). Dedicated 'fireman' should ensure continuous feeding of fuel in each chamber.

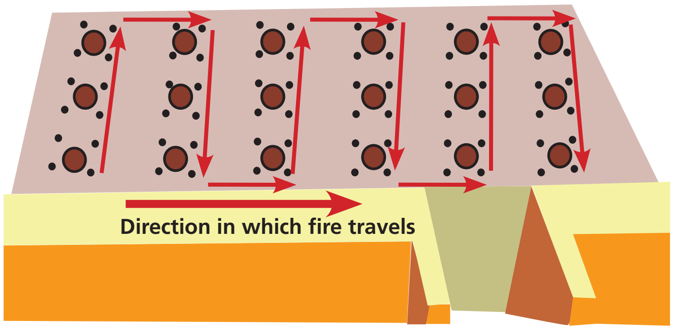
Table 4: Type of fuel to be fed in different chambers

Chamber	Chamber 1	Chamber 2	Chamber 3	Chamber 4	Chamber 5	Chamber 6
Temperature	750–850	850–950	1,000–1,025	1,000–1,025	800–900	500–650
Fuel type	Mixture of sawdust and coal	Coal	Coal	Coal	Mixture of sawdust and coal	Sawdust

Note: In induced draft zigzag kilns, only coal is used in the first chamber.

Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

Figure 26: Fuel feeding in six chambers at a time



Source: Manual on Cleaner Brick Kiln Technologies: Design, Construction and Operation, Greentech Knowledge Solution Pvt Ltd, 2016

Fuel is fed with the help of a spoon, the size of which varies with the kind of fuel used. Sawdust requires a bigger spoon than coal.

Coal is fed into the kiln in the powdered form.

Zigzag kiln technology has proved itself a worthy successor to the long-serving FCBTK technology. Both induced and natural draft zigzag kilns are more efficient—hence financially more viable—less polluting and environment-friendly than their older cousin. As the industry in India wakes up to the opportunities which retrofitting FCBTKs and converting them into zigzag kilns provide, crucial lacunae in the technical know-how reveal themselves. This design manual intends to cement these gaps.

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