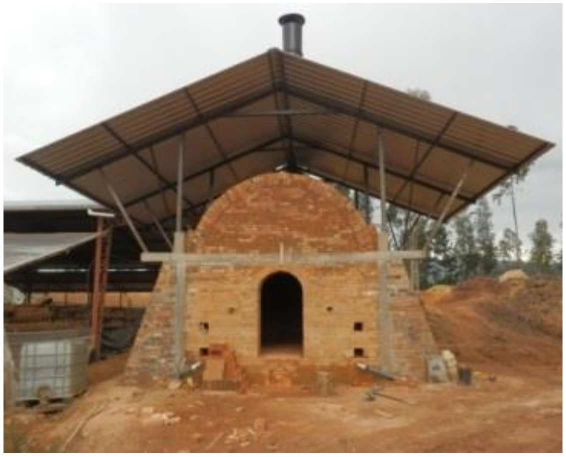
[EELA logo: Energy Efficiency in Brickworks]

PROGRAMME FOR ENERGY EFFICIENCY IN THE BRICK SECTOR IN LATIN AMERICAN TO MITIGATE CLIMATE CHANGE



Manual for efficient kilns in the brick industry

SEPTEMBER - 2015

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1 PRESENTATION

The objective of the Energy Efficiency in Latin American Brickworks Programme to Mitigate Climate Change (EELA – *Programa de Eficiencia Energética en Ladrilleras de América Latina para Mitigar el Cambio Climático*) is to contribute to the reduction of Greenhouse Gas (GHG) emissions in brickworks in the region and improve the quality of life for the neighbouring population. This project is financed by the Swiss Agency for Development and Cooperation (COSUDE – *Agencia Suiza para el Desarrollo y la Cooperación*) and executed by Swisscontact together with its partners in seven countries: Argentina, Bolivia, Brazil, Colombia, Ecuador, Mexico, and Peru.

Development activities of the EELA Programme include promotion of knowledge exchange, a mechanism that can disseminate technical information of interest to producers and technology and service providers as well as other players, like competent authorities, the academic sector and the like. Included in the information dissemination activities is promotion of a document describing the different types of kilns, which will be a reference on technology change for brickworks manufacturers. This Manual on Efficient Kilns for the brickworks industry is part of the set of tools and materials that are placed at the disposal of the companies so that they have technical and management information for cleaner, energy efficient, and primarily sustainable production.

The first part of this manual addresses topics on energy efficiency and efficient use of energy in order to then present information on the different types of kilns according to the type of process that the EELA Programme has identified in different countries where the programme has activities (Argentina, Bolivia, Brazil, Colombia, Ecuador, Mexico, and Peru).

Finally, an example of the concept of specific energy consumption is presented, which could help business owners better understand the technologies that will allow them not only to produce more efficiently but also allow them a more effective cost of energy used.

2 INTRODUCTION

This manual presents concepts and technical information about efficient kiln performance for the brickworks industry, including concepts and data related to energy use and quality of final product.

The technical information included in this manual comes from experience obtained within the framework of EELA Programme activities; results obtained from kiln operation have given rise to different positive aspects, like reduction in fuel use, which represents a reduction in greenhouse gas emissions through use of these models of energy efficient kilns. Likewise, this savings represents improvements in productivity and competitiveness for the brickworks companies besides the improvement in the quality of the final product.

3 ENERGY EFFICIENCY

The concept of energy efficiency is related to the optimal use of energy resources without altering production of the brickworks industry, seeking to explore different possibilities for reducing energy consumption that also represent advantages at the economic and environmental levels.

Energy efficiency can include simple, low-cost measures (thickening kiln walls, rearranging bricks inside the kiln, etc.), and other more complex and expensive measures (like changing to high-efficiency continuous kilns), but that can still be economically attractive. Therefore, the greater the use of techniques, equipment and more efficient processes, the less energy will be used and therefore a lower expense for this resource.

This specific energy consumption is obtained from the relationship between energy use (for example, burning firewood) divided by the production (reported per thousand pieces or tonnes), yielding an indicator that could reveal whether the company is making efficient use of energy and tell us how many potential producers could be supported for the improvement as related to the current production status.

Therefore, knowing that it is possible to save energy, it is important to evaluate some technological alternatives or options regarding types of kilns as presented herein, so manufacturers can choose the model of kiln that meets their expectations regarding improving their production process.

4 EFFICIENT ENERGY USE

Occasionally, some technological measures proposed for efficient energy use can seem economically unviable or impossible to apply; this is not so certain in practice, since some measures can yield additional achievements associated with energy savings which, in the end, is a great benefit for the producer. This is the case for technical measures that can be of benefit not just from savings in energy and/or fuel use, but from an increase in number of bricks produced, reduction in losses per lot of bricks produced and, in some cases, even an increase in production of first quality pieces. This could also lead to the possibility of producing new products or higher value pieces.

Therefore, it is important to account for all these benefits when thinking about investing in implementation of energy efficient actions and projects. In any event, project and modification implementation in a company should be preceded by a careful assessment of the advantages and possible disadvantages of the technologies. In the case of kilns, the heat produced by combustion is distributed to various points, but only one part is used for firing bricks and/or roof tiles. Most is lost in combustion gas (smoke) that is exhausted from the kiln through the chimney; another part remains stored in the walls and roof (or dome), and some is retained in the fired products, which is considered heat loss. Figure 1 shows the distribution of heat during the firing process.

Figure 1 Heat flow in brickworks kilns

[Insert heat loss diagram Flujo de calor en hornos de producción de ladrillas]

Pérdidas de calor en horno=Heat loss in the kiln

The numbers in the figure show the different situations related to heat loss:

1. Heat supply/fuel being burned
2. Loss of heat in combustion gases/chimney
3. Loss through openings and cracks
4. Losses through walls and roof/dome
5. Heat accumulated in the kiln walls
6. Heat accumulated in the pieces produced
7. Useful heat absorbed by the pieces being fired

Firing pieces in the kiln is the principal phase in product fabrication in terms of energy, generally making use of 95% of all thermal energy required by the company. The remaining 5% is related to the drying process only at companies that have implemented this process.

Therefore, the ideal is to be able to produce using the least amount of energy possible, which can be achieved by conveying less heat to the points identified in the above figure as losses or, alternatively, seeking some type of recovery of this heat to use it in the production process, as in the case of drying the pieces in a closed area.

5 KILNS FOR BRICK PRODUCTION

Brick Production

Brick production can be carried out in three ways:

a. Artisan: Bricks manufactured with predominantly manual procedures; mixing and moulding is done by hand. The brick produced this way is characterised by variations of one unit from another.
b. Semi-industrial: This is brick manufactured with manual procedures where the moulding process is carried out by basic machinery, such as an extruder that operates at low pressure to form the clay mass (pug). Semi-industrial brick is characterised by a smooth surface.
c. Industrial: Brick made with machinery that mixes, moulds, and presses or extrudes the clay mass. Brick produced industrially is characterised by its uniformity.

Artisan and semi-industrial production methods follow the same steps or sequences, only varying in the instruments, methods and tools utilised in production. The principal variation is in the moulding process, as previously explained, where extruders are used for semi-industrial brick where the clay mass is produced and thus obtain smooth-surfaced units.

The industrial process is different from the two first processes, not just in the use of machinery for the moulding process, but also in the use of more sophisticated kilns for the firing phase. These kilns have temperature control to achieve greater efficiency in production of clay units with a better quality in the end.

Classification of kilns according to process type

Depending on the brick production process, the kilns are classified as:

a. Intermittent kilns
b. Semi-continuous kilns
c. Continuous kilns

5.1 Intermittent kilns

These kilns have individual chambers where the products remain in the same position throughout the cycle, from placement for the firing process through cooling. The cycle scheme is:

Products placed
↓
Preheating
↓
Product firing
↓
Product cooling
↓
Product unloading

The amount of time for each of these operations is not identical and differs considerably depending on the product to be fired and the nature of the process. Following are descriptions of some of the kiln types currently in use up to highly efficient kilns like the portable kiln.

PAULISTINHA KILN

The *Paulistinha* kilns are typical in the brickworks industry in Brazil although they have a thermal performance that is lower than other types of kilns in the marketplace. It is estimated that they actually represent 15% of kilns in operation in the Brazilian brickworks industry, although with a decreasing trend in view of the gradual modernisation process the sector has been going through in recent years. *Paulistinha* kilns are used in different production regions of the country, with more in those regions with a lower technology level.

Estimate of number of companies and total production (*Paulistinha* kiln)		
Country	**Number of companies**	**Total production (trillions of bricks/roof tiles / year)**
Brazil	~1,100	~6.2

Figure 2. *Paulistinha* Kiln

[Insert fig. 2 – Horno paulistinha]

Description and operation

The *Paulistinha* kiln operates intermittently and has a masonry structure for firing bricks and roof tiles with no thermal insulation. It has a horizontal, rectangular section (6,0 to 8,0 m long, 3,5 to 5,0 m wide) and a height of some 3,0 m, with downward flow of hot gases, also called "down draught," through a sieve or grille in the floor (bottom plate). Generally from four to six burners situated in the side walls produce the firing heat. Burning the fuel establishes the upwards flow of hot gas towards the dome, from there it descends through the load where heat is exchanged, heading toward the bottom of the kiln where the grille is located for hot gas to pass through toward the channels in the bottom of the kiln. The hot gases pass through these channels toward the chimney.

Flow is controlled through “flow regulators” that can adjust internal kiln pressure. The *Paulistinha* kiln capacity can vary from 20 to 40 thousand bricks measuring 9x19x19 cm, equivalent to a processed mass of 36 to 90 t per firing.

Generally, these kilns operate in a connected formation, i.e., with another *Paulistinha* kiln next to the common lateral wall and interconnected with exhaust gas channels, seeking to use the firing heat or the first kiln for preheating the load to fire in the other kiln.

The firing cycle consists of approximately 12 hours to load, 20 hours to preheat, 18 hours to fire, 27 to cool and 12 to unload, for a total of approximately 90 hours or around four days, which can vary depending on firewood quality, type of clay, affected by the firing temperature, type of internal arrangement of the pieces, and other aspects. Generally the *Paulistinha* kiln can complete 6 to 7 firings per month (6,5 firings/month x 4 days/firing=26 days).

A kiln with 30 thousand (54 tonnes) per load of hollow bricks measuring 9 cm x 19 cm x 19 cm can achieve a monthly production of 195 thousand or 351 tonnes, although with an approximate loss of 30%, so the kiln actually produces 137 thousand first quality pieces per month (247 tonnes/month). Therefore, a ceramic industry with two *Paulistinha* kilns could produce 274 thousand or 493 tonnes of hollow bricks per month.

Performance

The *Paulistinha* kiln has heat losses due to high thermal inertia (large mass of the masonry structure) and radiation and convection through the side walls, vault and fuel feed holes, so it operates with low thermal efficiency levels, although less than arched kilns.

The *Paulistinha* kiln has specific firewood consumption in the range of 0,82 to 1,1 tonnes per thousand, equivalent to a specific energy consumption of 600 to 940 Kcal/kg, with an average thermal efficiency of 35%.

There are limitations on heat distribution in the load at the far corners of the kiln due to its rectangular shape, which represents a considerable level of losses, so the first quality product ratio is between 50 and 70%.

The firing cycle for this type of kiln shows the influence of the labour cost in the loading and unloading operations.

Cost

The *Paulistinha* kiln with a capacity of 40 thousand/load or 72 tonnes with internal dimensions of 8 m long, 5 m wide and 2,5 m high for a monthly production of 260 thousand, costs around R$ 90 thousand

(US$ 29.7 thousand) plus R$ 30 thousand (US$ 9.9 thousand) of civil work relative to the channelling of the gas draught and control system.

It has the advantage that it can be partially built with company labour, like the masonry part. Building a second kiln reduces the cost of channelling the gases.

Figure 3. *Paulistinha* kiln diagram

[Insert diagram –*Esquema horno Paulistinha*]

1. Burning fuel in the side of the kiln. 2. Hot combustion gases transfer heat to the bricks. 3. Gases released from kiln through intermediate parallel wall to the burner/openings near the ground. 4. Near the bottom of the wall parallel to the burner is the combustion gas duct directed toward the chimney. Extracción a la chimenea=Exhaust to the chimney; Puertas para cargar el ladrillo=doors to load bricks; Quemadores=burners.

Summary

- Outside dimensions: 7,0 to 15,0 m long, 3,5 to 6,0 m wide and around 3,5 m high;
- Capacity: 30 000 to 60 000 pieces;
- Products: bricks, roof tiles and floor tiles:
- First quality pieces: between 50 and 70%;
- Losses: between 5 and 8%;
- Specific firewood consumption: 0,82 to 1,1 tonnes/thousand (1,8 kg pieces);
- Specific thermal energy consumption: 600 to 940 Kcal/kg (2,5 to 3,9 MJ/Kg);
- Thermal efficiency: 35%;

Advantages

- Ease and ability of company labour and material to be used in construction;
- Attractive cost;
- Ease of operation;
- Heat recovery;
- Use of different types of fuel;
- Diversified production (bricks, roof tiles and floor tiles).

Disadvantages

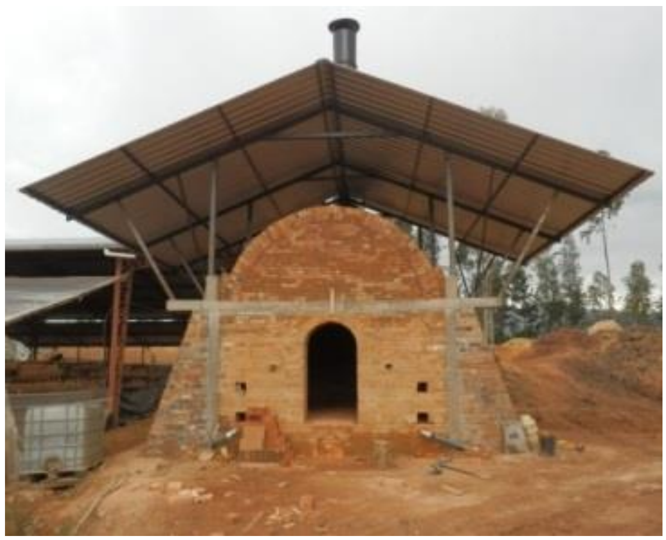
- Burning not very homogeneous (areas of the kiln with less heat);
- High specific energy consumption;
- Slow cooling;
- High labour input compared with other types of kilns;
- Relatively low percentage of first quality products.

DOWN DRAUGHT KILN

This model was adopted as the improved version of the open fire kiln in comparison with which the down draught kiln is more efficient with better heat distribution inside the kiln. This results in improved product quality. In addition, the down draught kiln meets the gas (NOx, SO_2 and CO) emission limits. The model was developed and built jointly with brick producers in Cusco, Peru (San Jerónimo) and later replicated in different areas of Peru and Ecuador.

Estimate of number of companies and total production (down draught kiln)		
Country	**Number of companies**	**Total production (billions of bricks/roof tiles / year)**
Peru	~4	~0.5
Ecuador	~7	~0.5

Figure 4. Down draught kiln



Description and operation

The down draught kiln operates intermittently and has a masonry structure without thermal insulation for firing the bricks and roof tiles. This type of down draught kiln is rectangular with a vault at the top and several openings along the side to inject air and fuel; the gas is exhausted through a sieve or grille in the floor (bottom plate). The operating principle is in the down draught or ascending flame. Combustion starts at the front, back and sides of the kiln.

At the beginning of the burning process, the heat produced rises to the roof of the dome. Then the heat goes down through the bricks and finally passes through the small openings in the floor. The combustion gases leave the kiln through an underground duct and flow to the chimney. They are forced out with a ventilator or by chimney suction. This kiln uses solid fuels like firewood, branches, pieces of wood and sawdust, and liquid fuels like oil and its derivatives. The complete production cycle in the kiln is: 04 – 07 hours to stack bricks, 12 – 20 hours for the firing process (including preheating) and up to 02 days for the cooling process. These periods depend on type of product, raw material and fuel used. Operating temperature varies from 800° C to 1000° C. Capacity varies by kiln size or size of the pieces, generally between 5000 to 12000 bricks.

Figure 5. Parts of the down draught kiln

[Insert figure 5 – Partes del horno de tiro invertido]

Horno de Tiro Invertido=Down draught kiln; Tapones=Plugs; Chimenea=Chimney; Tensores de la chimenea=Chimney guy wires; Base de chimenea=Chimney foundation; Mochetas=Piers (buttresses); Ducto de alimentación=Feeding duct; Mirilla=Viewer; Ventiladores=Ventilators

Performance

The down draught kiln has better energy yield than open draught kilns. This is achieved by the hot gases remaining in the chamber the longest time possible and firing the bricks uniformly.

Figure 6. Diagram of the down draught kiln

[Insert figure 6 Esquema del horno de tiro invertido]

The complete production cycle is: 04 – 07 hours to load bricks, 12 – 16 hours for firing process (including preheating) and up to 02 days for the cooling process. These periods depend on the type of product, raw material and fuel used. Operating temperature ranges from 800° C to 1000° C.

1. Cooking holes. Heat produced during combustion rises to the kiln roof. Air for the combustion process is injected with a ventilator. 2. Upon reaching the roof, the hot gases change direction and drop, passing through the bricks. 3. Next, gases exit the kiln through an opening in the bottom. 4. Finally the gases (smoke) move toward the chimney through an underground duct connected with the opening in the ground. This process can be natural or forced through an exhaust pipe.

Cost

The estimated time to build a kiln is approximately 30 days with support from a qualified foreman and 2 labourers.

Construction cost varies from US$ 6 000 to US$ 15 000, depending on the material provided by the owner and the labour which can be partially provided by the owner.

Summary

- Outside dimensions: length 5 – 6 m, width 3 m, height between 2,80 – 3,8 m;
- Chamber dimensions: production capacity: 800 – 1 100 tonnes per year, depending on size of the ceramic process. Example: 180 000 12 cm x 20 cm x 35 cm bricks, or 600 000 8 cm x 23 cm x 12 cm perforated bricks.
- Monthly capacity: 35 tonnes of compact ceramics per firing (3,5 kg per piece). An equivalent of perforated bricks can be processed; it can perform up to 5 firing cycles per month.
- Products: roof tiles, bricks and floor tiles.
- Specific firewood consumption: 0,15 to 0,2 kg firewood/kg of ceramic.
- Specific thermal energy consumption: Average: 3,10 MJ/kg of bricks or roof tiles fired (Range: 2,8 – 3,5 MJ/kg of bricks or roof tiles fired) (668 to 835 Kcal/kg).
- Average thermal efficiency: 31%
- Firing time: 12 to 20 h ours
- First quality pieces: 85%
- Losses: 2%

Advantages

- Moderate thermal energy use and GHG emission.
- Ability to burn several types of firewood (pieces, fine branches, wood blocks, briquettes, chips and sawdust); and ability to use liquid fuel.
- Low operating cost.
- Reasonably healthy production environment (principally during burning).
- Good productivity and production speed for small manufacturers.
- Homogeneous firing and low level of loss from breakage and cracks.

Best practices for efficient energy use

- Place dry bricks in the kiln;
- Use chopped firewood or sawdust;
- Use continuous feed and control air flow;
- Control the firing curve with thermocouples (temperature control);
- Possibility of using two or more parallel, interconnected kilns would improve thermal efficiency

ABÓVEDADO KILN (DOMED)

Abóvedado (dome circular) kilns are used in Brazil, Colombia, and Peru. They are popular in the Brazilian brickworks industry although they have a thermal performance that is lower than other technological alternatives on the market. It is estimated that they make up between 30% and 40% of the kilns used in the Brazilian and Colombian brickworks industry with a stable participation trend, while use is decreasing in production areas with more advanced technology and growing in production regions lacking technology. Currently, they are used in all productive areas of the country.

Figure 7. *Abóvedado* kiln

[Insert figure 7. Horno abovedado]

Description and operation

The *abóvedado* kiln is an intermittent masonry kiln without thermal insulation used for firing bricks and roof tiles. It has a horizontal circular section some 7 m in diameter, height of 2,5 m and vaulted roof, with descending flow of hot gas draught, also called "down draught," through the sieve or grille in the floor (floor plate).

From four to six burners are used, which are placed equidistantly on the lateral perimeter. The fuel burn establishes an upward flow of hot gases toward the circular dome roof from which they descend through the load, exchanging heat with it, going toward the floor plate of the kiln where the sieve is located that passes the hot gases to the channels at the bottom of the kiln.

From there, the hot gases (smoke) move toward the chimney which induces the draught of the combustion gases although this can also be done by extractors. The flow is controlled by flow regulators that can adjust the kiln's internal pressure.

Generally these kilns are interconnected with a dryer through underground channels, which enables heat recovery from the kiln's cooling phase. Thus all the hot air to be exhausted from the kiln is directed toward drying.

The operation generally has more than one of this type of kiln to achieve a more continuous production for the company, including heat recovery for drying.

The capacity of an *abóvedado* kiln may vary, generally from 30 to 50 thousand 9 cm x 19 cm x 19 cm bricks (value equivalent to a processed mass of 44 to 90 tonnes per firing) or up to 100 thousand, as in the case of 80% to 90% of colonial roof tiles (1,1 kg/piece).

The operation cycle includes 12 hours to load the kiln, 20 hours to preheat, firing of 18 to 40 hours, cooling for at least 24 hours, and unloading another 12 hours for a cycle of practically 4 days. This time may vary depending on the quality of the firewood, type of clay, firing temperature, method of internal distribution of the pieces, moisture in the firewood and other factors. This fairly long operation cycle can influence the cost of labour and productivity of the loading and unloading operations.

Generally an *abóvedado* kiln can complete from 6 to 7 firings monthly, produce from 180 to 500 thousand monthly, depending on type of piece fired.

Figure 8 Diagram of *abóvedado* kiln

[Insert figure 8: Esquema del horno abovedado]

1- Heat produced during the combustion process moves toward the kiln roof.
2- Once they reach the vault, the combustion gases move down, passing through the load toward the kiln floor plate.
3- Then the gases leave the kiln through small openings in the floor plate.
4- Finally the gases move toward the chimney through an underground duct; this process can be natural or forced by an extractor.

Calor/flujo de gases=Heat / Gas flow; Techo abovedado=Domed roof; Gases de la combustión=Combustion gases; Hornilla=Burner; Cenizas=Ashes; Solera=Floor plate; Puerta para carga/descarga=Loading door

Performance

The circular kiln generally has an acceptable yield since it is a kiln with a discontinuous system (by lots). The circular section has fewer limitations on heat distribution in the load compared to the *Paulistinha* kiln since there are no corners in the kiln, which leads to slightly lower losses. On the other hand, heat distribution in the vertical section is not very homogeneous. Temperature in the upper part of the kiln rises rapidly, which does not happen in the lower part near the floor where it might not even reach desired temperature levels. So, the ratio of first quality products is generally more than 60%, but rarely exceeds 80%.

Because it is an intermittent kiln, the *abóvedado* kiln also takes a lot of time to heat and cool, i.e. it has a large thermal inertia. Add to this the loss in heat from radiation and convection through the lateral walls, roof (dome), and fuel feed holes, and energy performance is not very high.

The *abóvedado* kiln has a specific firewood consumption that varies from 0,75 to 1,0 tonnes per thousand which gives specific energy consumption in the range from 552 to 884 Kcal/kg (2,31 to 3,7 MJ/kg) and an average thermal efficiency of 38%.

Summary

- Outside dimensions: 5 to 11 metres diameter; 2,2 to 3,0 metres high;
- Number of burners: from four to six;
- Capacity: 30 000 to 110 000 pieces (40 to 130 tonnes per load); monthly capacity: 180 to 600 thousand (240 to 710 tonnes/month);
- Products: roof tiles, bricks and floor tiles:
- Firing cycle and time: firing time from 20 to 40 hours, depending on type of clay and firewood used, and complete cycle of 3,5 to 4,5 days;
- First quality pieces >60%;
- Losses of 2 to 5%;
- Specific firewood consumption: 0,75 to 1,0 tonnes/thousand (1,8 kg pieces);
- Specific Heat consumption: 552 to 884 Kcal/kg;
- Average thermal efficiency: 38%;

Cost

An *abóvedado* kiln with a capacity for 50 thousand/load of 9 cm x 19 cm x 19 cm bricks (90 tonnes), with internal dimensions of 8 m (diameter) and 2,5 m height, monthly capacity of 300 thousand/month) costs around R$ 100 thousand(US$ 33 thousand), plus R$ 30 thousand (US$ 9,9 thousand) of civil works for the gas draught channels and control system.

Advantages

- Easy to build.
- Possible to build using company labour and material.
- Easy to operate.
- Attractive cost.
- Heat recovery.
- Use of different types of fuel and diversified production (bricks, roof tiles and floor tiles).

Disadvantages

- Unequal heating between the upper and lower zones.
- High specific energy consumption.
- High labour input compared to other types of kilns.
- High loss index due to firing deficiencies and product manipulation.
- Lower quality product in the area near the floor.
- Unhealthy conditions for unloading the kiln (high internal temperature and dust cloud).

Best practices for efficient energy use

- Use cut up firewood.
- Use continuous, automatic firewood feeding.
- Control the firing curve with thermocouples (temperature control);
- Recover heat in the cooling stage.

MOBILE KILN

Mobile kilns are used in Brazil, Peru, Bolivia and Paraguay. Their use began in Brazil less than six years ago due to a greater supply of domestically manufactured or competitively priced imported ceramic fibre, considering that thermal insulation in these kilns is one of the decisive cost factors in the final value. A significant increase in the number of these kilns in the market in Brazil is projected in coming years, taking into account the more than ten manufacturers in the country, primarily in productive regions where environmental emissions control is stricter and the supply of biomass is more difficult and costly. These suppliers are expanding their offer in other countries.

This type of kiln has considerable technical, economic and environmental advantages – they provide a reduction in the demand for thermal energy, better ratio of first quality product, reduction in labour cost, increase in production speed, reduction in emissions, and ability to produce roof tiles, floor tiles or bricks, among others.

Estimate of number of companies and total production (mobile kiln)		
Country	**Number of companies**	**Total production (billions of bricks/roof tiles / year)**
Brazil	~100	~1,0
Peru	4	Information unavailable
Bolivia	2	Information unavailable
Paraguay	5	Information unavailable

Figure 9. Mobile kiln

[Insert figure 9 Horno metálico móvil]

Description and operation

The mobile kiln uses an intermittent cycle. It is composed of a portable body with a metal structure (sides and roof) and internal lining of special ceramic fibre (15 cm thick). This structure moves over rails, connecting over two or three stationary burner bases, also called fixed platforms, on ceramic floor tiles that make up the seines of grilles of the kiln through which hot gases from burning are extracted (kiln draught).

The internal lining of the kiln with ceramic fibre (low-density, lightweight material) reflects the heat and reduces its absorption by the structure of the portable part, providing low thermal inertia to the combination which translates into: reduction in structural heat loss, increase in heating speed and reduction in cooling speed.

Generally 6 to 12 burners are attached on one side of the portable part, which can operate with different types of fuel: firewood or sawdust, powdered biomass and even gas with greater capacity kilns having burners on both sides.

The portable structure of the kiln (weighs between 40 to 150 tonnes) can have variable width, length and height, according to the production capacity desired per firing. The structure is actuated through an electrical hydraulic system which moves the kiln (portable structure) from one load of bricks to another. Thus, after firing a first load, the kiln moves to another load located adjacent. This movement takes about 5 minutes.

Companies with sufficient drying capacity can use a third platform, which enables an increase from 12 monthly firings (with two platforms) to 15 using three platforms. The loading doors can be overhead, horizontal with two parts or vertical or compound opening (vertical/overhead), depending on the height available in the structure.

Figure 10. Mobile kiln diagram

[Insert figure 10 esquema del horno metálico móvil]

Chimenea=Chimney; Puertas metálicas levadizas o basculantes=Lifting or swinging metal doors; Chimenea=Chimney; Carga=Load; Estructuras metálicas=Metal structures; Quemadores=Burners; Puerta metálica=Metal door; Rieles=Tracks; Roldanas=pulley wheels; Ducto subterráneo para escape de gas=Underground duct to exhaust gas.
1. The brick load is stacked on the floor. 2. Firing takes 15 to 25 hours. 3. After firing, cooling the load begins – to 250° C (12 hours) and the kiln is then moved to the next load of bricks.

Performance

The firing time for portable kilns is on the order of 15 to 25 hours and cooling from 12 to 15 hours, yielding a 36- to 45-hour cycle. In generally terms, a firing cycle can be considered on the order of 2 days, which depends on the amount of dry material available to fire.

Portable kilns can be left idle, for example, on Sundays, which reduces the cost of overtime. Thus, considering only 25 days of operation monthly, an average number of 12 firings per month is supported with two platforms and up to 15 firings/month for three platforms (if there is sufficient dry material); in this case the actual cycle would be less than 02 days.

Firing is controlled by the temperature signal from thermocouples installed in the upper part of the kiln so that feeding combustion air and fuel are controlled (rotating valves or screw-type feeders for solid fuels or different types of valves for liquid or gas fuels).

The mobile kiln has a lower demand for thermal energy.

It also has a specific firewood consumption of 0,47 to 0,53 tonnes per thousand, equivalent to 397 and 419 Kcal/kg (1,6 to 2,1 MJ/kg) and average thermal efficiency of 56%.

Note that there can always be variations in specific consumption based on the firing temperature of the clay, type of fuel (gross calorific value, humidity and particle size), burner type, type of firing control, placement of pieces in the kiln, and the like. Another positive aspect is the ability to use heat from firing and cooling for the drying phase.

By allowing an extremely rapid heating curve, something that speeds up production, care must be taken to place well-dried pieces in the kiln. Otherwise, cracks can appear in the products.

Labour can be better used, reducing the time between firing cycles. That is, after unloading one base for the kiln, respecting the 12- to 15-hour cooling period of the load, the kiln can immediately begin the heating and firing process for the next base (adjacent base). The reduction in time lost in loading and unloading the kiln increases labour productivity by around 30%. In other words, it significantly reduces the company's operating cost.

Figure 11. View of the mobile kiln

[insert figure 11 – Vista del horno metálico móvil]

Cost

A smaller capacity (50 thousand/load of 9 cm x 19 cm x 19 cm bricks with a volume of 15 m x 5 m x 3 m and monthly capacity of 600 thousand/month) mobile kiln can cost almost R$ 350 thousand (US$ 115,5 thousand), plus R$ 150 thousand (US$ 49,5 thousand) in civil works for the platforms, seines and draught channels for the dryer and hood in the chimney, totalling R$ 500 thousand (US$ 165 thousand).

Almost 40% (R$ 140 thousand – US$ 46,2 thousand) of the value of the kiln (R$ 350 thousand – US$ 115 thousand) corresponds to thermal insulation with ceramic fibre and R$ 210 thousand (US$ 69,5 thousand) to the metal structure, masonry, electrical installation, control system, installation, etc. Larger kilns (24 m x 8 m x 3.5 m) for 150 thousand/firing or 1.8 million/month and two platforms) can cost approximately R$ 1 million (US$ 330 thousand).

Summary

- Outside dimensions: length 15 m to 25 m; height from 3,5 m to 4,0 m, and width from 4,5 m to 6,6 m;
- Number of burners: six to twelve, which can be on both sides;
- Chamber dimensions: 200 to 600 m^3;
- Load capacity: 50 000 to 120 000 pieces (80 to 200 tonnes per load);
- Monthly capacity: 600 000 to 1 500 thousand (1 100 to 2 700 tonnes/month);
- Products: roof tiles, bricks and floor tiles;
- Specific firewood consumption: 0,47 to 0,53 tonnes/thousand (1,8 kg pieces);
- Specific thermal energy consumption: 397 to 519 Kcal/kg (1,6 to 2,1 MJ/Kg);
- Average thermal efficiency: 56%
- Complete firing cycle: 2,0 to 2,5 days;
- Firing time: 15 to 25 hours;
- First quality pieces: >90%;
- Losses: <1%.

Figure 12. Mobile kiln: load ready (left) and metal doors

[insert figure 12 Horno metálica móvil: lote listo (Izq.) y puertas metálicas]

Advantages

- More than 90% first quality products;
- Speed of firing can be modulated;
- Adapts for different types of raw material and products;
- Low loss index and second quality material;
- Good energy performance;
- Heat recovery;
- Low thermal energy demand;
- Use of different types of fuel;
- Better health conditions in the production environment.

Disadvantages

- Costly construction;'
- More complex operation than other types of kilns (full-time operation to control kiln pressure, rhythm of heat progress through chambers);
- Requires care not to damage the ceramic fibre.

Best practices for efficient energy use

- Use completely dry raw material;
- Use firewood in pieces or sawdust;
- Use continuous fuel feeding;
- Firing control curve using thermocouples;
- Recover heat from cooling process.

5.2 Semi-continuous kilns

These kilns produce a greater load than the intermittent kilns and in some cases loads very close in size to those produced by continuous kilns. The whole load of bricks can be placed completely in the firing chamber without reserve storage. Therefore, the firing progress rhythm within the kiln depends on the chamber capacity and efficiency with which the heat is moved throughout the chamber. The operation of semi-continuous kilns is similar to the intermittent kiln with a significant difference being that air exhaust always occurs at the end where the bricks go in. Semi-continuous kilns approach continuous kilns at the operating level the longer the firing cycle lasts; otherwise they are similar to intermittent kilns. Semi-continuous kilns occasionally are groupings of intermittent kilns tending toward continuous operation.

HOFFMANN KILN

Hoffmann kilns were developed in the mid-nineteenth century based on the pioneering idea of heat flow in relation to the load, allowing preheating the cold load in the back chamber with the heat from the exhaust gases from the front chamber of the kiln, which was a considerable advantage in reducing fuel requirements. In that era, the Hoffmann kiln established a gain in thermal performance compared to intermittent kilns although it was not the appropriate kiln to produce roof tiles.

The use of this kiln gradually increased in the region primarily beginning in the 60s so that in different regional brick producing centres its presence began to dominate, primarily in those states with high levels of brick production development. It is estimated that Hoffmann kilns represent between 15 and 20% of kilns installed in brickworks industries in the countries. On the other hand, due to its high cost, it is continuously less considered in expansion projects or in creating new companies. Estimated data on the use and production of the Hoffmann kiln in Brazil and Peru are shown below.

Estimate of number of companies and total production (Hoffmann kiln)		
Country	**Number of companies**	**Total production (billions of bricks/roof tiles / year)**
Brazil	~120	~1 440
Peru	~5	~60

Description and operation

The length of the Hoffmann kiln can vary from 60 to 120 metres, with widths around 3,5 m and height of 2,8 m. Generally the number of chambers is from 15 to 25 with capacities in the range of 10 thousand each. Thus an average rhythm of 04 chambers fired produces 40 thousand per day or 1.200 thousand/month), that is, this Hoffmann kiln can operate its set of chambers between 04 and 06 times per month.

The structure of the Hoffmann kiln is entirely masonry with thick walls to resist the thermal shock of constant heating and cooling operations that subject its structure to constant expansion and contraction, representing a considerable mass that absorbs part of the heat from burning the fuel. Another reason for the heavy structure is the need to support the extreme weight of the domes of the tens of kiln chambers.

The firing is produced from the upper part of the kiln by manually feeding fuel or with a type of cart with burners, one burner at each feed hole. The cart moves hourly as the burning process advances. The process occurs in a way that a set of burners (three fire openings) works for some six hours.

Figure 13. Hoffmann Kiln

[insert figure 13 – Horno Hoffmann]

Figure 14. Hoffmann kiln diagram

[insert figure 14 – Esquema del horno Hoffmann]

1. Módulo del horno=Kiln module; 2. Piso=Floor; 3. Chimenea=Chimney; 4. Cenizas=Ashes; 5. Quemadores=Burners; Sección=Section

Performance

The operation of the Hoffmann kiln depends on never running out of dry material to be fired because that runs the risk of losing the production rhythm and compromises thermal stability, energy consumption, and production quality. Specific consumption increases or decreases depending on the speed of the fire's progress. If the fire progress is quick, the kiln tends to use less fuel; so to change from a four-day cycle to a two-day cycle, the firing time can be reduced to less than half, but it will require very careful attention to the operation, besides being impossible for producing bricks that have a heavier unit weight. It also depends on the type of clay processes, running the risk of breaking down the load inside the chamber. This has to do with the temperature gradient and with the load shrinking, that is, when the part next to the fire is hotter, it can fall in that direction. Therefore, there is an impediment factor to firing roof tiles in Hoffmann kilns which would require a firing speed limited to the point that it would be uneconomical.

The Hoffmann kilns depend on a well-projected chimney in front of the interconnection with the tens of kiln chambers for the draught system of the exhaust gases. There are many cases where the natural draught is not established satisfactorily, necessitating the placement of a forced exhaust system which influences the internal pressure of the kiln and the firing process, emphasising that each chamber have a local exhaust duct connected to the central draught duct connected to the chimney, but interconnected with a system of registers to regulate internal kiln pressure.

A Hoffmann kiln usually consumes between 50 and 70% less than the conventional intermittent kiln, placing the specific fuel consumption in the range of 0,6 to 0,8 tonnes/thousand. In this performance range, the specific energy consumption falls between 418 and 637 Kcal/kg (1,7 to 2,6 MJ/Kg), with the respective average thermal efficiency of 50%.

Firing cycle

The total firing cycle for each chamber in the Hoffmann kiln can vary from 02 to 04 days, depending on burning speed, which depends on the type of product processed. It can have an average value of three days per chamber, two days with the chamber closed and a half day more to load and a half day to unload.

In the two days with the chamber closed, an average of 06 hours of firing per chamber is considered, as well as 21 hours of heating and another 21 for cooling the load, making a time of 48 hours with the chamber closed, plus 12 hours with the chamber loading and another 12 hours to unload with a total cycle of 03 days for each chamber, also remembering that 04 chambers are firing in a single day. A kiln with 20 chambers can achieve a complete cycle in five days, for execution of six cycles per month in the kiln, processing some 120 chambers per month or some 1 200 thousand per month.

The firing cycle for this type of kiln makes the influence of the labour cost felt through the loading and unloading operations, which also negatively influences productivity due to the longer cycle.

Cost

A good capacity Hoffmann kiln (1 200 thousand/month, equivalent to 2 200 tonnes/month) can cost around R$ 800 thousand (US$ 264 thousand). This production would need 20 chambers with internal dimensions of 3,0 m long, 2,5 m deep and 2,5 m high (internal volume of 18,8 m^3/chamber and about 10 thousand/chamber) and monthly capacity of 1 200 thousand /month, with the advantage of using some company labour for construction as well as its masonry material.

Summary

- Outside dimensions: length – 60 to 120 metres; height – 2,5 to 3,0 metres; width – 3,5 to 4,5 metres; number of chambers: 12 to 116, with firing on top;
- Load capacity: 10 000 to 12 000 pieces (18 to 22 tonnes per load);
- Monthly capacity: 800 to 1 200 thousand/month (1 440 to 2 160 tonnes/month);
- Products: bricks and floor tiles;
- Complete firing cycle: 03 days;
- Firing time: 06 hours per chamber; average firing of 04 chambers per day (40 to 48 thousand/day);
- First quality pieces: >90%;
- Losses <2%;
- Specific firewood consumption: 0,6 to 0,8 tonnes/thousand (2,2 kg pieces);
- Specific thermal energy consumption: 418 to 637 Kcal/kg (1,7 to 2,6 MJ/Kg);
- Average thermal efficiency: 50%.

Advantages

- First products more than 90%;
- Firing speed can be regulated;
- Adapts to different types of raw material;
- Low loss index and second quality material;
- Good energy performance;
- Low thermal energy demand;
- Heat recovery;
- Uses different types of fuel.

Disadvantages

- Costly construction;
- More complex operation than other types of kilns (continuous control of kiln pressure, the rhythm of heat advancing between chambers);
- High labour cost;
- Only brick production;
- Requires excessive product manipulation;
- Over burnt product on the bottom and unburned product in the dome;

Best practices for efficient energy use

- For the kiln project it is worth considering lighter walls and roof which reduces thermal inertia of the combination;
- The adjustable chamber connection registers with central exhaust must be in good condition to keep the central duct in depression and not to promote losses from leaking hot gases.
- Firing should preferably be performed with chopped firewood which provides constant feed of kiln heat and can be done automatically;
- It is also worth using the kiln structural heat to reduce moisture in the firewood, storing it beside the kiln walls;
- The initiation of burning must be slow;
- The loading platform must be high and at a good distance to avoid putting out the fire;
- Pieces in the first chamber must be very dry. Excess moisture in the pieces slows fire passage, causing cracks, shattering and deformation;
- The fire should begin after the chamber is completely heated. If it begins too soon, there will be excessive moisture in the chamber, slowing the kiln rhythm;
- To evaluate moisture in the chambers, a common practice is to insert a metal bar to check for drops of water on it.

CEDAN-TYPE CHAMBER KILN

Cedan-type chamber kilns were developed about 15 years ago and represent an evolution from the conventional chamber kilns and Hoffmann kilns. Since 2008 they spread through the Brazilian brickworks industry due to their technical characteristics and economic advantages. Currently an estimated 150 kilns of this type are in operation in the country, with potential for expansion. This kiln is quite appropriate for roof tile manufacturing. It provides a high index of first quality pieces, good homogeneity of products, low loss index and low use of thermal energy.

Estimate of number of companies and total production (Cedan kiln)		
Country	**Number of companies**	**Total production (millions of bricks/roof tiles / year)**
Brazil	~150	~1500

Figure 15. Cedan Kiln

[Insert Figure 15. Horno Cedan]

Description and operation

The Cedan kiln consists of multiple interconnected chambers sharing internal heat, providing a semi-continuous operation. The most common placement consists of a set of 6 or 8 chambers on each side of the kiln, interconnected laterally with passages under the floor (seine) and internal passages. The capacity of these chambers can vary from 25 000 to 40 000 pieces (32 to 52 tonnes) according to the internal dimensions and type of product being fired.

The semi-continuous operation of the Cedan kiln is characterised by the fact that one chamber is constantly firing. That is, while a determined chamber is firing, the next and adjacent chambers, already loaded with material for firing, receive residual heat taken from the chamber being fired. Therefore, from two to five subsequent chambers are preheating. Meanwhile, the chamber before the one being fired is simultaneously cooling the fired load, blowing air from the outside. This air exchanges heat with the hot pieces and moves toward the chamber in the firing phase, acting as hot combustion air, which also contributes to a better energy yield.

The combustion gases flow upwards in the combustion chamber to the dome of the kiln and passing through openings in the upper part of the wall that separates the combustion chamber where the ceramic pieces are located. In this compartment, the flow of hot gases diverts to the bottom, being directed underground, crossing a sieved floor. From there, the heat is sent toward the burner of the adjacent chamber through openings under the floor, passing the wall that divides the chambers.

This entire circuit, re-routing several times, makes the heat move slower, which is good for proper sinterisation of the product, as well as keeping particulate material from the combustion gases inside the kiln and reducing atmospheric emissions. The chimney is installed on the side of the kiln, together with the outside wall and could need an exhaust, primarily if the chimney is not very high.

Lower capacity Cedan kilns have only one line, establishing a production and sequence where, after firing the last chamber, the first chamber is fired again. Greater capacity kilns use the two-line firing system (in cycle) with firing both sides of the kiln (chambers on two sides) like the two-line Hoffmann kilns. That is, the next firing always occurs in the chambers that are in the direction of the flow.

The firing cycle of Cedan-type kilns does not consider the kiln loading and unloading periods, since these operations take place while the kiln is preheating, firing and cooling the upper and lower chambers. Therefore, as mentioned, while one chamber is in the firing phase, the chamber in front is in the cooling phase and the next (ensuing) chambers are in the preheating phase while others further on (already fired) are being unloaded.

The operating cycle of this type of kiln affects the labour cost in the loading and unloading operations (04 to 06 labourers) and firing (01 stoker per shift), which affects the production cost and productivity.

The firing time for each chamber can vary from 8 to 36 hours (15 hours on average), depending on the characteristics of the raw material in the final product (roof tile, brick or floor tile). The firing temperature in the kiln should be between 800° and 950° C.

It can average around 30 firings per month, generating a production capacity of 900 thousand per month (ref: 85% of colonial roof tiles 1,1 kg/piece and 15% hollow bricks at 2,4 kg/piece) or 810 tonnes/month.

Fuel in the form of firewood, chips or sawdust is fed from the top of the kiln (roof) either continuously or in lots (intermittently).

Firing is controlled by the temperature signal from thermocouples installed inside the chambers, facilitating control of the combustion air feed and fuel itself (rotating valves or screw-type feeders).

Figure 16. Cedan kiln diagram

[Insert figure 16 – Esquema del horno Cedan]

1. Combustion process initiates in the first chamber. 2. Hot gases produced by combustion in the first chamber move to the next chambers where the pieces for firing are being preheated. 3. Combustion gases are passed through an underground duct toward the chimney. The process is repeated from one chamber to another. Cycle lasts around 3,5 days, reaching temperatures of 800-950° C. Firing lasts on average 15 to 18 hours. Chimenea=Chimney; Cámara en fase de enfriamiento=Chamber in cooling phase; Bóveda=Dome; Cámara en fase de quema=Chamber in firing phase; Gases calientes=Hot gases; Abertura para la alimentación de combustible=Fuel feed port; Cámara en fase de calentamiento=Chamber in heating phase; Puerta para carga Loading port; Abertura en la solera=Opening in floor plate; Gases calientes=Hot gases; Gases de combustión fluyen hacia la chimenea=Combustion gases flow toward the chimney.

Performance

The Cedan kiln has good thermal efficiency with a production cost that is not too high and provides a solution when seeking better sustainability (better thermal energy use, less gas and combustion waste emission), although it represents a labour requirement for loading and unloading the chambers, which affects the cost of operations.

Cedan kilns have low energy consumption due to heat recovery between internal chambers. The first quality piece ratio is above 90% and production losses below 2%.

The Cedan kiln has a specific firewood consumption of between 0,4 and 0,45 steres per thousand, specific energy consumption in the range of 409 to 545 Kcal/kg (1,7 to 2,2 MJ/kg) and average thermal efficiency of 54%.

It must be indicated that this specific thermal energy consumption can vary depending on the firing temperature of the clay, type of firewood/biomass used (gross calorific value, moisture and particle size), type of firing (continuous or intermittent), type of firing control, arrangement of pieces inside the kiln, and other aspects.

Cost

The investment cost of a Cedan kiln with a 12-chamber production capacity (900 thousand/month) is around R$ 400 to 500 thousand (US$ 132 to US$ 165 thousand), considering the use of the company's own labour for masonry, made with solid bricks that can be manufactured at their brickworks.

Summary

- Outside dimensions: Length – 36 to 50 m; height – 4,2 m; width: 15,0 to 24,0 m;
- Chamber dimensions: 3,0 x 5,3 to 12,0 x 3,0 to 3,5 (height, depth, width);
- Chamber capacity: 25 000 to 50 000 pieces (32 to 65 tonnes per load);
- Monthly capacity: 670 to 1.400 thousand (855 to 1 800 tonnes/month);
- Products: roof tiles, bricks and floor tiles;
- Specific firewood consumption; 0,4 to 0,45 tonnes/thousand (1,8 kg pieces);
- Specific thermal energy consumption: 405 to545 Kcal/kg (1,7 to 2,2 MJ/kg);
- Average thermal efficiency: 54%;
- Firing time: 15 to 18 hours, depending on type of clay and firewood used;

- Preheating time: 01 to 02 chambers per day;
- First quality pieces >90%;
- Losses <2%.

Advantages

- Low thermal energy use and GHG emissions;
- Production flexibility with loads of around 30 thousand pieces;
- Ability to burn several types of firewood (pieces, twigs, extruded dowel, briquettes, chips and sawdust);
- Low operating cost;
- Ability to recover heat for drying;
- Reasonably healthy conditions in the production environment (primarily during the firing);
- Good productivity and production speed;
- Homogeneous firing with low level of loss due to breaking and cracks.

Disadvantages

- Relatively high investment cost;
- A little more complex operation.

Best practices for efficient energy use

- Continuous and automated feeding of firewood and/or chips;
- Fire control curve using thermocouples.

5.3 Continuous kilns

Continuous kilns appeared the most profitable solution for manufacturing ceramic products. The continuous operation of the kilns is characterised by uninterrupted firing and the ability to complete different phases without varying the production rhythm. The most typical example is the tunnel kiln.

TUNNEL KILN

Tunnel-type brickworks kilns have been in use for decades, although in reduced proportion due to the high investment cost and production scale it demands (> 2 thousand tonnes/month), many types outside the companies' reach. Even so, construction barriers for this type of kiln have been going down to the extent that its advantages are looking much more attractive.

In Brazil, the current forecast is that the number of tunnel kilns with adequate capacity (>2,000 tonnes/month) will double in the next ten years, taking into account that there are more than ten manufacturers in the country with a considerable number of orders, primarily in production regions where gas and particle emission environmental standards are stricter and the supply of biomass is more difficult and costly, as well as the labour. These are reasons to consider it an interesting alternative. There are some data estimating the use of this kiln in Brazil and Peru.

Estimate of number of companies and total production (Tunnel kiln)		
Country	**Number of companies**	**Total production (billions of bricks/roof tiles / year)**
Brazil	~70	~1,0
Peru	~ 5	~0,08

The tunnel has considerable technical, economic and environmental advantages that promote a reduction in the demand for thermal energy, increase in ratio of first quality product, reduction in labour cost, increase in production speed, reduction in emissions, ability to produce roof tile, floor tile or bricks, among others.

Figure 17 Tunnel kiln

[Insert fig. 17 – Horno túnel]

Description and operation

The tunnel kiln has a unique stationary body with a length varying from 50 to 120 m and two side walls (height of 2 m to 3 m) and a straight roof or internal dome. Inside, the carts containing products for sinterising run through the tunnel.

The kiln can be divided into 3 zones – preheating, firing and cooling. The raw product enters at the end of the preheating zone and exits at the other side in the cooling zone.

In the first zone, the products placed in carts or buggies are preheated, traversing a temperature curve up to 300° C. The raw product is preheated by the passage of a cross-current of combustion gases from the firing in the central part of the kiln. These hot gases exchange heat with the load and move toward the chimney, generally located on the roof at the entrance to the kiln (preheating zone).

Next, the carts enter the firing zone where the burners are located (placed laterally or in the roof). During this phase, the temperature of the product exceeds 300° C. up to 750/950° C. depending on the type of clay processed. Finally, in the third and last zone, the products enter the cooling cycle until they exit the kiln. Cold air from outside is injected in this stretch while hot air is extracted that can feed the dryer and/or be used for combustion air in the firing zone.

This entire configuration of continuous operation with several heat recoveries gives the kiln a high energy yield and productivity.

Figure 18. Carts in the Tunnel Kiln

[Insert Figure 18 – Vagonetas en horno Túnel]

Performance

Tunnel kilns enable large-scale production with lower thermal energy requirements (0,4 to 0,43 tonnes of biomass per thousand bricks of 1,8 kg each (9 cm x 19 cm x 19 cm), considering the use of hot air from the cooling zone for the dryers or the combustion zone (firing). The tunnel kiln needs less labour input for operation and maintenance based on its automation.

Firing is controlled by the temperature signal from the thermocouples installed in the upper part of the kiln so as to control feeding combustion and fuel (rotating valves or screw type feeders, endless for solid fuel, or different types for liquid and gas fuels).

Tunnel kilns are built of masonry with metal structure reinforcement to anchor the generally straight roof. Internally, the firing zone is lined with a refractory insulating material (refractory ceramic brick or ceramic fibre) in order to reduce heat loss.

The specific energy consumption of the tunnel kiln ranges from 341 to 422 Kcal/kg (1,4 to 1,7 MJ/kg) and has an average thermal efficiency of 66%. Modern tunnel kilns with ceramic fibre insulation can achieve energy consumption approaching 1,0 MJ/kg).

Figure 19. Tunnel Kiln diagram

[Insert Fig. 19 – Esquema horno túnel]

Zona de combustión=Combustion zone; Zona de enfriamiento=Cooling zone; Flujo de carros=cart flow; Quemadores=Burners; Zona de calentamiento=Heating zone; Zona de quema=Firing zone; Zona de enfriamiento=Cooling zone

Cost

A tunnel kiln with a capacity of 2 000 tonnes/month (1 100 thousand/month of brick 9 cm x 19 cm x 19 cm) can cost around R$1,2 million (US$ 400 thousand without automated fuel feed control).

Figure 20. Diagram of cross-section of tunnel kiln and load

[Insert Fig. 20. Representación de la sección transversal de un horno túnel y de la carga]

Source: Dadam, 2005 (upper); Dadam and Nicolau, 2006.

Aislamiento tipo 1=Type 1 insulation; Aislamiento tipo 2= Type 2 insulation; Pared externa – techo=Outside wall - roof; Pared interna – bóveda=Inside wall - dome; Carga=Load; Soporte de Carga=Load support; Pared externa lateral=Inside lateral wall; Pared interna – techo=Internal wall - roof; Aislamiento=Insulation; Gases del Horno=Kiln gases; Pared interna – lateral=Internal wall - lateral; Hornillas=Burners; Vagoneta=cart; Gases de la base=Gases from the base

Summary

- Outside dimensions: length 50 to 120 m; height 2 to 3 m and width 4 to 8 m;
- Number of burners (in case of solid fuel): 6 to 12 (generally on both sides);
- Monthly capacity: >1 100 thousand /month (> 2 000 tonnes/month);
- Products: roof tiles, bricks and floor tiles;
- Specific firewood consumption: 0,4 to 0,43 tonnes/thousand (1,8 kg pieces);
- Specific thermal energy consumption: 341 to 422 Kcal/kg (1,4 to 1,7 MJ/kg);
- Thermal efficiency: 66%;
- First quality pieces: >95%;
- Losses: <1%.

Advantages

- Drastic reduction in thermal energy demand and carbon emissions;
- Kiln can adjust to the company's needs, although always more than 2 000 tonnes/month;
- Uses various types of fuel;
- Ability for total heat recovery;

- Less labour input;
- Better health conditions in the production environment;
- Greater productivity;
- Higher speed production;
- Homogeneous firing (>95% ratio of first quality material);
- Less product manipulation (fewer losses);
- Processing all types of products (bricks, floor tiles and roof tiles).

Disadvantages

- Increased cost;
- Continuous operation (cannot stop), requires dry material for firing
- Setting up requires precision;
- Requires well-trained people for fine adjustments;
- Requires care in maintenance with the electronic firing command system;
- Requires care with impacts against the internal ceramic fibre lining;
- More difficulty if production stops.

Best practices for efficient energy use

- Use completely dry material;
- Use good quality fuels: gas or liquid. In the case of solid fuel, reduce particle size (pellets or dust);
- Use continuous fuel feeding;
- Control firing curve using thermocouples;
- Recover heat from the cooling phase.

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7 APPENDICES

APPENDIX 1. SPECIFIC ENERGY CONSUMPTION

Specific energy consumption is a highly important index in assessing energy performance of an industry or of its phases of production process and even its principal equipment. It is also important in assessing the results of implementing energy efficiency measures (fuel and electricity) so that results can be compared before and after applying a new project or equipment.

The evolution of specific energy consumption values over time allows follow-up of energy performance and comparison with other companies. These values also make it possible to compare different technology, for example, the different types of existing kilns. For this, it is necessary to correctly establish these indices with detailed measurements.

Specific energy consumption refers to the amount of electric or thermal energy used in manufacturing a determined product. Some types of specific energy consumption indices that can be established in the company are shown below.

Thermal energy

Stere (st) or cubic metre (m^3) or kg of firewood per tonne (t) of final product or per thousand (1 000 pieces). Ideally the control unit should be Kcal/kg of final product (kilocalorie per kilogram), but this requires that units be converted, as shown in the example presented later.

Electric energy

kWh/t of clay processed or kWh/t of product leaving the kiln or kWh/t of final product (discounting the losses). Although we have a monthly use measure (kWh) for electricity reported on the electric utility bill, for firewood and other types of biomass (agricultural and industrial waste) a more careful analysis would be required.

The sale of biomass is by the t (tonne) or st (stere) – unit that considers the volume of 1 m^3, but with the possibility of large variations in mass based on the variation of the shape of firewood (presence of branches, average diameter). The energy content is also influenced by the type of wood used and the amount of moisture. So, the mass of a stere of firewood can vary generally from 150 to 400 kg; evaluating the specific energy consumption of a manufacturing process based on the volume in st is completely inaccurate since it is necessary to convert this measurement in steres to a fuel mass (kg or t).

In summary, specific thermal energy consumption control using the traditional st or m^3 of firewood/thousand produced should be avoided considering the large possible variations in firewood mass per st or m^3, as well as the product mass per thousand. Ideally, the firewood used should be weighed (sample weight) and production obtained (calculation of mass produced) giving values in kg (or tonnes) of firewood per kg (or tonne) of production.

The values necessary to calculate the specific energy consumption should be reliable and strictly measured. In addition, some necessary information may be obtained from technical tables that the manufacturer should have available, like those shown below.

Table 1. Lower calorific value (LCV) of different biomasses

Biomass	LCV	Biomass	LCV
Firewood (40% water)	2 400	Huasai palm seed	2 400
Dry firewood (12% water)	3 680	Brazil nut shells	2 400
Eucalyptus branches	4 300	Huahuasú palm bark	2 400
Eucalyptus	3 800	Cashew nut shells	2 400
Pine cones	4 000	*Mimosa tenuiflora*	2 400
Dry sawdust (20% water)	3 500	*Caesalpinia pyramidalis*	2 400
Sawdust/bagasse briquette (50/50)	4 430	*Acacia angico*	2 400
Bagasse (20% water)	3 200	Algorrobo	2 400
Rice husks (12% water)	3 300	Cashew tree trimmings	2 400
Cocoa husks	4 000	Charcoal	2 400

LCV: Lower Calorific value (Kcal/kg)

Table 2. Biomass moisture vs. Lower Calorific Value (LCV)

Moisture %	LCV	Moisture %	LCV
0	4 756	50	2 085
10	4 221	60	1 551
20	3 687	70	1 016
30	3 153	80	482
40	2 619	90	-

If information is not available about the specific mass of the firewood or biomass residue (kg/m^3), the business owner should weigh the firewood to be used in the factory (for example weigh from 3 to 6 cubic metres).

APPENDIX II. EXAMPLE OF SPECIFIC ENERGY CONSUMPTION CALCULATION

A company produced 1 000 thousand /month with 40% roof tiles (1,1 kg/piece) and 60% dry bricks (1,8 kg/piece). This means that the company produces 400 thousand/month of roof tiles (440 tonnes/month) and 600 thousand/month of hollow bricks (1 080 tonnes/month) resulting in a total production of 1 520 tonnes/month. Therefore, the percentages indicate a final production mass ratio of 71% hollow bricks and 29% roof tiles.

If the company uses 1 000 m^3 of firewood (1,0 m^3 of firewood per thousand) per month with a specific weight of 250 kg/m^3 or stere, it will require 250 000 kg of firewood mass (1 000 x 250) for that month. So now we have a consumption ratio of 250 tonnes of firewood per 1 520 tonnes of production, given the specific consumption value of 0,164 t of firewood/tonne of product (250 000 ÷ 1 520).

If this firewood has a specific consumption value of 3 000 Kcal/kg (see table for type of firewood), it means that the company needed 750 million Kcal (= 250 000 kg x 3 000 Kcal/kg). If we divide this value by the monthly production in kg (1 520 000 kg), we obtain the specific thermal energy consumption of 493 Kcal/kg which should be the reference value for the company to verify its thermal energy performance periodically.

Firewood consumption of the dryer, if there is one, can be added to the calculation, making the index even more realistic and precise. So, if the firewood consumption in the kiln were 50 m^3/month, the total firewood consumption for the company would be 1 050 m^3/month and, following the previous logic, we would obtain a specific thermal energy consumption of 518 Kcal/kg. Thus, with this reference value, the company can monitor its fuel consumption weekly or monthly or even compare it with his competitors or partners.

Other similar indices can be established referring to the mass of clay processed or final production less losses, since they will all enable a more analytic reading of the energy operation over time

APPENDIX III. SUMMARY TABLE

KILNS		Caipira	Paulistinha	Abovedado	Hoffmann	Cedan	Mobile	Tunnel
Specific firewood consumption (st/thousand)		1,2 to 1,5	1,25 to 1,7	1,15 to 1,6	0,9 to 1,2	0,6 to 0,7	0,7 to 0,8	0,6 to 0,65
Specific Energy Consumption (Kcal/kg)	*Lower*	795	583	536	418	409	397	341
	Greater	1104	914	860	637	545	519	422
Average capacity per firing	*thousands*	23 to 40	30 to 60	60 to 110	35/chamber	28/chamber	50 to 120	100 to 130 ton/day
First quality pieces	*%*	20 to 40	50 to 70	60 to 80	90	90	90	95
Thermal Efficiency	*average (%)*	27	35	38	50	54	56	66
Production losses	*average (%)*	10 to 20	5 to 8	2 to 5	<2	<2	<1	<1
Products		Te/La	Te/La/Ba/LH	Te/La/Ba	Te/La/Ba/LH	Te/La/Ba/LH	Te/La/Ba/LH	Te/La/Ba/LH
Heat Recovery *yes/no*		No	Yes	Yes	Yes	Yes	Yes	Yes
Particulate emissions		Considerable	Little	Little	Very little	Very little	Very little	Very little
Cost	*US$ thousands*	8,3 to 10	33 to 50	33 to 50	250 to 283	133 to 166	150 to 183	366 to 433

Caipira: Open kiln with fixed walls. Abovedado: Dome circular
Te: roof tiles; La: Brick; Ba: floor tiles; LH: hollow brick.
Using 3,65 Kcal/kg as the base for firewood calorific value, a variable mass of 1 240 to 2 500 kg of ceramic products per thousand, allowing biomass fuel variability of 340 to 445 kg per tonne and the assumption that the useful heat for firing 1,0 kg of ceramic material is 250 Kcal, according to the assumptions for each type of kiln.