SUSTAINABLE SMALL SCALE BRICK PRODUCTION: A QUESTION OF ENERGY

Introduction

The construction sector uses up the earth's resources and contributes to its pollution. This is an increasing concern. Whilst other components of construction, such as transport or building itself, also play a role, it is generally agreed that the production of building materials is the main culprit. Materials production, for instance, requires around 75% of the energy used in construction. In India, it is estimated that the brick industry produces 22% of the CO_2 emissions by the construction sector and requires around 27% of the energy used in building materials production. This is because the small and medium scale sectors are predominant in the South and are generally more polluting than modern large-scale industry.

Figure 1: Boiler waste is sieved and used as a fuel for firing brick clamp kilns at Kurewasekwa Cooperative in Epworth, Harare. Photo: Practical Action / T. Schilderman

One possible strategy towards more sustainable construction is to promote the use of alternative, low-energy or renewable materials, such as earth or bamboo. The production of simple earth blocks only requires around one thousandth of the energy needed to fire bricks. Even when earth is stabilized with cement it is no more than a sixth per kg of material, and usually less. Where possible, Practical Action takes this on board in its housing projects.

A combination of factors, though, including urbanization, attitudes and inappropriate building standards are generating a rise in demand for conventional materials such as steel, bricks and cement, which do have a substantial negative environmental impact. This trend is hard to reverse and, in Practical Action's opinion, it is therefore equally necessary to adopt a second strategy, aimed at mitigating this impact. That is the focus of this paper.

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technical brief

The issues

The production of conventional building materials impacts on the environment in several ways. Poor quarry management generates lots of waste and leaves behind disused pits. Smoke and dust affect the health of workers and neighbouring residents alike. The biggest impact is, however, usually caused by the energy used in their production. This is where Practical Action concentrates most of its efforts.

Leaving aside the metal industry, which affects fewer countries, the binders and heavy clay industries are the principal energy users. Practical Action has worked for over 20 years on the production of these materials in a dozen countries. During the past decade, its emphasis has been on the production of bricks and lime by Small and Medium Scale Enterprise (SMEs). Practical Action is particularly interested in SMEs, because they:

- generate a lot of income: for example in Bangladesh alone, brick production accounts for over 200 000 jobs;
- often produce the bulk of these materials, for example SMEs account for 85% of total brick production in Sri Lanka;
- have lesser transport requirements which saves energy;
- are often the greatest polluters, and improving them is therefore likely to generate greater environmental benefits

The production of bricks by SMEs often relies on fuelwood as its main source of energy. Wood consists of nearly 50% carbon; if burnt completely, one kg of wood releases around 1.8 kg CO_2, the main greenhouse gas. Moreover, each tree cut down for fuel reduces the "CO_2 sink", the environment's capacity to absorb this gas from the air. The inefficient use of woodfuel by SMEs thus contributes to the global environmental crisis, though this is nowhere near the negative contribution attributable to vehicle emissions.

This issue also affects the sustainability of many SMEs. In Malawi, for instance, the number of people active in lime production is reported to have decreased from 2374 in 1989 to below 500 in 1998, largely because of fuelwood scarcity. Fuel costs can amount to 50% of total production costs. Energy efficiency, therefore, lies at the heart of the commercial viability and sustainability of SMEs.

The challenges for Practical Action are therefore to improve the energy efficiency of brick production at the SME level and explore alternatives to wood as fuel. This can be achieved by scaling up towards larger and more modern production methods, but that would displace many SMEs and cause large-scale redundancies. Besides, the environmental impact would not necessarily have been less but different. Instead, Practical Action has opted for working with SMEs in cleaning up their act.

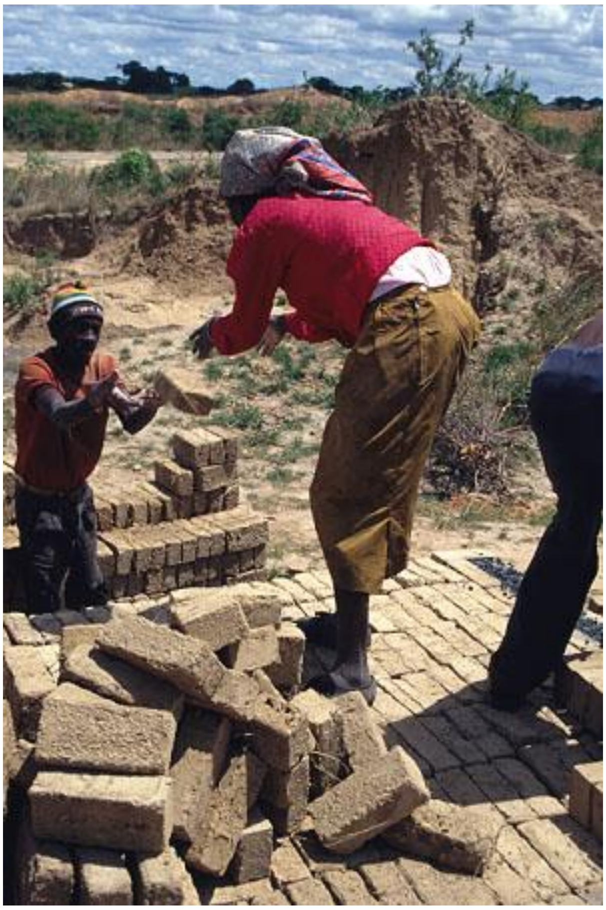

Figure 2: Brick makers are shown building the clamp kiln prior to firing, Zimbabwe. Photo: Practical Action / Janet Boston.

Brick production
The energy question
The theoretical energy requirement to fire bricks has been put by Barriga et al. at 0.85 MJ/kg of fired brick. A lot more energy is used in practice, as a range of sources illustrate:

Kiln types	Fuel types	Energy use (MJ/kg fired brick)	Energy efficiency (%)
Traditional clamp	Biomass	3.0 – 8.0	10- 28
Intermediate clamp	Coal, coke	2.0 – 4.5	19 - 42
Scotch kiln	Biomass	1.5 - 7.0	12 - 59
Vert. Shaft kiln	Coal…	0.8 – 1.4	60 – 100
Bull's trench kiln	Coal….	1.1 – 4.0	21 - 77
Hoffmann kiln	Coal, gas, oil	1.5 – 4.3	20 - 56
Tunnel kiln Co	Oil, gas	1.5 – 2.0	45 - 56

Information on energy use in brickmaking, though, has largely been collected in a random fashion, making data such as the above no more than indicative, For example, a report could state that a certain enterprise uses 0.7 cubic yards of fuelwood to fire 1000 bricks. Without knowing the type of wood, its moisture content, weight and calorific value, nor the weight or moisture content of the bricks and the quality of the final product, we do not know much about energy efficiency.

A standard to compare energy efficiency
When attempting to improve energy efficiency and to share lessons with other researchers or producers, there is an obvious need to have a more precise method of collecting energy data. The method described below was evolved by Practical Action and has since been applied in Peru, Zimbabwe, Sudan and Ecuador.

An important component of this standard method is the specific firing energy; this can be derived as follows

1) Total energy used (Mj) = mass of fuel (kg) x net calorific value of the fuel (MJ/kg);
2) Drying energy (MJ) = wet mass of green bricks minus dry mass of green bricks x energy required to evaporate water (2.591 MJ/kg);
3) Firing energy (MJ) = total energy (MJ) – drying energy (MJ);
4) Mass of fired brick (kg) = average fired mass (kg) taken on a sample of at least 24 bricks x number of bricks fired;
5) Specific firing energy (MJ/kg) = firing energy (MJ)/mass of fired brick (kg)

Apart from the calorific value, which usually requires laboratory testing, the other data is relatively easy to collect and calculate. This is not, however, the only piece of information required to decide whether firing has been efficient or not. First of all, there are observations to be made with respect to kiln type, location of fuel in the kiln, length of firing, kiln siting, and climatic conditions. Furthermore, to enable comparison between different sites, we need to know how easily a soil can be fired. Practical Action has classified soil types as high temperature. (vitrifying above 1000°C), medium temperature (vitrifying between 950 °C and 1000 °C) and low temperature (vitrifying below 950 °C). This refractoriness of soils can be tested by firing small cones, with a height of around 70mm and a base of around 15 mm across, in a suitable test kiln with a controllable firing temperature. The vitrifying temperature is the one at which the cones bend or slump.

It is also necessary to check how good the fired bricks are, since a kiln can seem efficient, but produce underfired bricks. Testing certain properties, such as strength or porosity, is inadequate for that purpose, since they are not only a function of firing. Measuring temperatures against time in various locations of the kiln is a possibility, though an expensive one. Practical Action opted for the use of Buller's bars (sometimes called Holdcroft bars or thermometry). These come in a range of numbers, deforming at different temperatures sustained for a period of time. Stands holding four different bars are placed at strategic locations in the kiln to provide a good indication of the heat-work done in these locations.

Research achievements

In Zimbabwe, demand for bricks far outstripped supply by the mid 1980's, as a result of rapid urbanization. This created opportunities for SMEs to supply the urban market with bricks of better quality than the traditional "farm bricks". Unfortunately, since SMEs relied on wood to fire their clamps this caused a scarcity as well as deforestation.

Practical Action's initial intervention was, in partnership with a local NGO, to establish a small brickworks near Chegutu. The main innovation here was a coal-fired clamp, considered an appropriate technology for SMEs because of its low investment cost. In such clamps, fuel is spread throughout, which increases efficiency. Although coal-fired clamps were known elsewhere, they had to be adapted to the scale of production in Zimbabwe, typically 20000-30000 bricks per clamp. This adaptation was successfully achieved.

In order for bricks to meet the standards prevailing in urban areas, improvements in moulding were needed as well. A number of options were experimented with: two imported presses, an imported moulding table and a locally produced one. All of these have proven to be effective, but output from the tables is lower than from the presses. On the other hand, the imported equipment is rather expensive, a disadvantage overcome by the local model. It is worth noting that better clay preparation, moulding and drying reduce wastage and energy use.

A later innovation has been the replacement of coal by boiler waste. This is freely available from certain industries, for which disposal causes problems. Due to the inefficiency of the boilers, the ash retains a high calorific value. The use of this residue has greatly increased the viability of certain brickworks. At Kurarama, for instance, it reduced energy inputs to just 8% of overall production costs.

The work in Zimbabwe is now in its dissemination phase. By 1996, more than 60 separate SMEs were reported to use coal-fired clamps, which is a good indicator of the viability of the technology. Unfortunately, data collection on energy use and efficiency and environmental impact has been rather haphazard, due to time pressures on staff and the initial absence of a standard methodology for assessing energy efficiency. From a recent environmental impact study of brickmaking in Zimbabwe, we may derive that traditional wood-fired clamps use 2,05MJ/kg of fired clay to dry and fire the bricks, whilst releasing 0,255 kg CO_2/kg of brick. Compared to Table 1, these figures are low, a sign that most bricks are probably underfired. Comparable figures for coal-fired

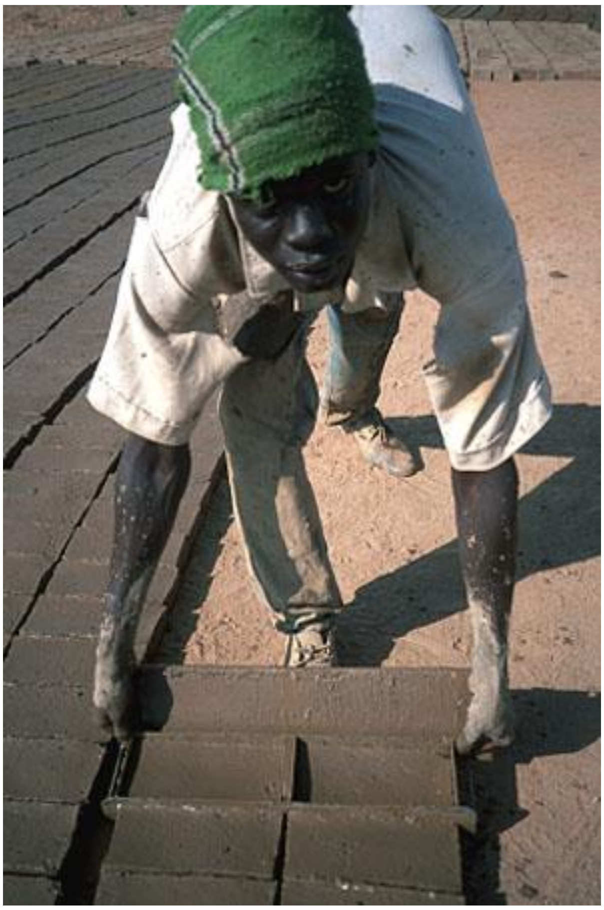

Figure 3: Brick-making using improved kiln at Kassala, Eastern Sudan. Releasing the moulds and laying bricks for drying. Photo: Practical Action / Mohammed Majzoub.

clamps are 2.04 MJ of energy, 0.233 kg of CO_2 and 0.04 kg of SO_2 per kg of fired brick, which again are low. Firing with boiler waste reduces the energy use to 1.56 MJ/kg whilst releasing 0.251 kg CO_2/kg of brick. Without data about soil types and brick quality, these figures are no more than indicative of energy efficiency. In fact, some of the larger kilns in Zimbabwe do use more energy per kg of fired brick but their end product is also better. Using coal instead of wood only has marginal direct environmental benefits but leaves the trees as a CO_2 sink. Using boiler waste has the additional advantage of getting rid of a residue, the disposal of which can cause environmental problems.

Practical Action's intervention in Peru is more recent. Initial studies revealed differences in brickmaking technologies according to the three distinct regions of Peru: a desert coast, bare highlands, and the forest. The predominant firing technology is the Scotch kiln. The coast and the Andean regions face severe fuelwood shortages, whilst this fuel is used, albeit inefficiently, in the forest region. Practical Action started by applying some of the lessons learnt in Zimbabwe, that is, to adapt Scotch kilns to coal firing. This was not entirely new to Peru, in a few locations some coal was already used together with wood. Contrary to Zimbabwe, the coal used in Peru is third grade, largely because that is the only alternative affordable to brickmakers. Its quality is quite variable, which can cause problems, and will require the development of a simple quality test.

The initial research, around Piura, replaced only half of the wood by coal which was spread through the kiln, whilst wood was fired in tunnels underneath. This improved energy efficiency and reduced costs by 7% to 15%. The next step was to attempt full substitution by coal, using hand moulded balls of coal dust and clay in the tunnels, which reduced energy costs by half. Overall, energy consumption has come down from around 3.8 MJ/kg of fired clay in the traditional kiln to an average 2.1 MJ/kg when firing mainly with coal. Still, wood was used to ignite the kiln. Further research has revealed that this could be substituted by the use, for a couple of hours, of oil burners. In Ayacucho, some brickmakers already had a habit of using 12% to 20% by weight of coal, with the remainder being eucalyptus wood, with a typical energy consumption of 2.5 MJ/kg, Initial research here, reversed the fuel type proportions, and energy use halved but this resulted in some underfiring and needed to be adjusted upwards.

Fieldwork in Peru is now researching the use of other residues as fuel. Around Piura, rice husks are already used but their high ash content obstructs air flow in the kiln, leading to lower quality bricks. That problem will have to be addressed. Practical Action is currently learning the lessons from the traditional use of rice husk as a fuel and adapting kilns to use it more effectively. Other residues with potential to be used as a fuel in Peru including cotton stalks and sawdust have now been used to replace firewood completely. Sawdust is incorporated into the brick mass during production by brick makers in Piura and ignited using a burner fired by recycled oil.

In Sudan, the brick industry consumes over half of the fuelwood nationwide. In the East, where Practical Action works around Kassala, good wood has to be brought from the Blue Nile region, far to the South. The only available local wood is mesquite, which is less than 10 cm thick and therefore not a very satisfactory fuel. In Sudan, bricks are usually made by slop moulding, which is fast, but produces a poor quality brick. Some cowdung is mixed in the clay; this is made possible because cowdung is not used as a fertilizer at the moment. Bricks are fired in large clamps, usually containing more than 100 000 bricks.

Practical Action's intervention, dating from 1995, has so far focused mainly on improved moulding and the question of fuel. Slop moulding was replaced by the much drier sand moulding, using a slightly larger mould to produce standard size bricks. 'The resulting bricks are better, much in demand and fetch a price 10 to 20% higher than traditional bricks. Sand moulding is, however, slower and since brick moulders are paid piecemeal, it is important that some of the extra income benefits them. In the 1999 season the Shambob Brickmakers Co-operative, supported by Practical Action, sold more than 1 million of these improved bricks and faced demand for many more.

The research into fuels has different strands. A downdraught vaulted kiln, of 20 000 bricks capacity, was built and equipped with oil burners. The initial indications are that this could make substantial savings on fuel costs, but the kiln is still not yet functioning optimally, and will require some further work to obtain reliable data.

Practical Action is also studying the various parameters involved in the use of cowdung, so as to optimise it. In Sudan, cowdung is considered a good additive, because it increases plasticity, reduces breakage and being an internal fuel, seems to increase efficiency, adding too much, however, reduces strength and increases porosity. The optimum range seems to be between 20% and 30%. Using sand moulding and increasing the proportion of cowdung enabled Practical Action to reduce the energy share of production costs from 53% to 36%, whilst saving 44% on wood. At the same time, the share of labour costs increased from 42% to 59%, allowing higher payments for sand moulding.

Further experimental firings used bagasse as fuel. This residue is widely available from sugar factories in Sudan. If can be used as a mixture in the clay or burnt as briquettes. The latter are made from bagasse and molasses as a binder. The briquettes are formed in a soil block press. One test clamp of 55 000 bricks used 0.114 kg bagasse per brick (instead of cowdung), which comes to 12.4% of overall costs, and 6827 kg wood, fired in the tunnels, representing 15%; the overall energy use amounted to 2.3 MJ/kg of fired brick. Another clamp; of 63000 bricks, used the same amount of bagasse in the bricks, in this case amounting to 11.5% of overall costs, and a mixture of 1439 kg of wood and 3325 kg of bagasse blocks in the tunnels, these costs being 20%. The overall energy use here was 176 MJ/kg of brick, which is perhaps a sign of underfiring. Thus, the energy share of production costs was further reduced. Unfortunately, in this case transport represented a substantial part of the costs of bagasse based fuels and greater savings can be expected in locations closer to sugar factories. Practical Action has: however, firmly established that it is possible to replace at least half the fuelwood by bagasse blocks. Initial tests to replace three quarters of the wood are promising.

Finally, Practical Action started working with brickmakers in Sri Lanka in 1998. Preliminary studies indicated that there are more than 5000 brick-works in the country, producing over 500 million bricks per year; 85% of which by SMEs. There is widespread use of both clamps and Scotch kilns, two-thirds of which are in the 10000-25000 brick range. The brick and tile industry in Sri Lanka consumes in excess of 150 000 tonnes of fuelwood per year, half of which is rubberwood. Some producers have reverted to using offcuts from sawmills and a few use rice husk. The principal objective of Practical Action's project is to investigate to what extent residues such as sawdust, coir dust and rice husk can be used as fuelwood substitutes, which links it closely to the work in Peru and other international research.

Work has started with three pilot producers in the Kandy region. This has involved the incorporation of sawdust, at about 20% by volume, in brick clays; this has improved the drying process and reduced cracks. Thus, the number of broken bricks has reduced greatly to less than a tenth of the original 3% to 4%. In addition, saw dust with some firewood was placed in channels incorporated higher up in the kiln, a tradition also known in Ecuador. So this limited experience has led to a reduction in firewood use by 21% and to an equivalent saving in the cost of fuel; the reduced wastage led to further savings.

Conclusion

The brickmakers Practical Action works with have few marketing problems; markets for bricks are generally expanding and improved quality bricks in particular satisfy the increasing demand from urban markets. Their viability and sustainability, however, is threatened by a fuelwood crisis affecting the environment and the people in many locations. One key strategy therefore is to increase the fuel efficiency of SMEs.

Over the years, it has become clear that for small brick producers their immediate livelihoods are of greater concern than the long-term sustainability of their production. For them, cost efficiency is of crucial importance, rather than energy efficiency or perhaps the long-term environmental impact. As such, they were quick to grasp the advantages of using boiler waste in Zimbabwe or sawdust in Sri Lanka and Peru.

SMEs often manufacture low quality bricks; underfiring, to save on fuel costs or due to the dwindling supply of fuel, is an important factor in this. Their product quality needs to improve if they are to make the most of the emerging urban markets. Better kilns and firing methods are one factor in product quality but improvements in other aspects of the production process also help. Product pricing clearly affects market viability and demand, suggesting that there is a case to be made for the production of different grades, to suit a range of market segments.

Energy data from brick production are often unreliable and incomparable; a standard method for assessing energy efficiency is required to make systematic progress and share lessons. Similarly, there are no standard methods to assess the environmental impact of SMEs, and Practical Action is developing those in practice. Given that it took some time to develop and apply the methods, more reliable results are only now starting to come in.

At the SME level, it seems reasonable to aim for a firing energy figure of around 2 MJ/kg of fired brick of acceptable quality; this amounts to an energy efficiency of around 40%. The drying energy will have to be added to that. This type of production will release at least 0.25 kg CO_2 per kg of brick. What these targets represent in terms of energy savings or reduced pollution depends on the baseline situation in each case.

A second strategy for the survival of SMEs is fuel substitution. It is possible to use coal in clamps or Scotch kilns, and there is great scope to use residues, mixed in the brick clay, loose or briquetted. Use of alternative fuels can have a considerable impact on the commercial viability of SMEs. As yet, the environmental impact of using residues as fuel is somewhat unclear, but since their current disposal is often by burning or dumping, it is assumed to be no worse than burning wood.

So far, there is insufficient reliable data on the comparative efficiency of different kiln types. The figures provided in Table 1 are at best indicative, but once the standard method is applied more widely, they will become firmer. The coal-fired VSK (Vertical Shaft Kiln) has proven to be very efficient in China, but its dissemination elsewhere in Asia has run into problems. A Swiss-funded project in India, has, however, proven to be more successful in its dissemination of the technology and has also generated further improvements to the kiln. In theory; bigger kilns are more efficient.

Finally, improvements elsewhere in the production process, such as better soil selection and preparation or better moulding and drying, not only help to produce more marketable products, but also to reduce waste and save energy.

Summary

Building materials production is the greatest single contributor to pollution in the construction sector. Developing countries are facing an increasing demand for conventional materials, such as fired clay products. A large proportion of these are produced by SMEs, generating income but often significant amounts of pollution too. This paper looks at brick production as an example of a conventional building industry with a substantial environmental impact. The sustainability of SMEs producing these materials is under threat. A significant factor in this is their inefficient energy use and reliance on wood as their main source of fuel.

After many years of research and development, supported mainly by the UK's Department for International Development (DFID), the Intermediate Technology Development Group (now Practical Action) has concluded that standard methods are required to assess energy efficiency and environmental impact. Improvements to kilns and their operation enable energy efficiencies in SMEs to reach at least 40%. Furthermore, it is possible to substitute fuelwood by coal, charcoal and oil. The use of residues, such as rice husk, bagasse or sawdust, as fuel also has great potential. Savings on fuel are crucial in enhancing the economic sustainability of SMEs. Better firing, combined with other improvements in production, can raise the quality of the end product, increase access to markets and improve commercial viability.

Practical Action has experience that suggests that the introduction of radically different technologies, such as vertical shaft kilns (VSKs), are more likely to fail, due to non-technical problems within SMEs since they require more comprehensive development and support services. The participation of producers is an essential factor in successful technology development or adaptation. The existence of a market for a range of different qualities of bricks is equally important. Fortunately, in most locations, brick producers do not seem to suffer from a lack of demand, whilst that helps to maintain their commercial viability, it may actually diminish their willingness to change.

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