# A Study Toward Energy Saving in Brick Making: Part 1 - Key Parameters for Energy Saving

**S. Prasertsan and T. Theppaya**
Department of Mechanical Engineering
Prince of Songkla University
Hat Yai, Thailand 90110

## ABSTRACT

The state-of-the-art of brick making in Asia was studied and it was found that in many countries the industry is using energy inefficiently. Experiments determining the effects of firing temperature and firing time on the mechanical properties of the brick were carried out. The firing time does not affect the compressive strength and water absorption properties. Higher firing temperature increases the compressive strength but has no affect on the water absorption. It was found that the minimum firing temperature for clay-brick transformation is 600 °C. The specific energy is in the range of 569-966 kJ/kg brick for the firing temperature between 600 and 900°C. The mechanical properties of four-hole hollow bricks with 7 different hole sizes were studied. The production of light brick (high area to mass ratio) is suggested in order to reduce the energy consumption without significant loss of mechanical properties.

## 1. INTRODUCTION

Brick is a common construction material used everywhere. As urbanization is expanding in developing countries, more bricks are needed for the infrastructure development. Attempts to improve the brick firing technique in developing countries were carried out by adopting western initiatives. However, there are certain factors such as scale of industry, labor and local attitudes that limit the success of western technology implementation. Moreover, the brick used in Asia is fired at lower temperature compared to the brick produced in developed countries. Firewood and rice husk are the main fuel sources for brick firing because they are abundant in the developing countries. The use of fuel oil was encouraged to slow down the use of wood from the forest [1], but this was limited to some oil-rich countries. Expansion of local industries creates an increasing need of firewood for energy supply. As a less value-added commodity, brick production cannot compete with the others in the firewood price war. It is a pressing need, therefore, to reduce the firewood used in brick firing. Fundamental knowledge on brick making is needed to enhance the understanding and pave the way to the reduction of firewood consumption. The essential knowledge reported in this paper concerns the current technology and the role of firing time and temperature on the properties of brick. It also suggests a basic design, operation of the kiln, and the dimension of the brick that could reduce the firewood consumption.

## 2. OVERVIEW OF BRICK MAKING TECHNOLOGY IN ASIA

Brick making in developing countries is traditionally a small and family-based industry. The brick kilns can be seen scattered in the rural areas wherever the raw materials (clay and sand) and fuel (biomass) are available. Technologically, the change for improvement received very little attention. The kilns are divided into three major types namely, updraft kiln, downdraft kiln, and continuous kiln (Figs. 1 - 3). A study in Indonesia suggested that the fuelwood fired updraft kilns should be changed to fuel oil-fired downdraft kilns in order to reserve the forest of the country [1]. Fuel and kiln were developed independently in the Philippines. Rice husk gasification systems were coupled to small shuttle kilns [2] while the moving-fire kiln were introduced in large factories [3]. In Thailand, and believed to be applicable to other countries, various forms of kilns are found ranging from updraft scotch kiln to the energy-efficient continuous (moving ware) kiln. A literature survey which traced back to the study in 1966 by the Institute for Applied Science Research [4] revealed that no R&D on energy saving in brick production was carried out in Thailand. The survey in 1993-1994 showed that the specific energy consumption in brick firing is 2-3 MJ/kg brick which accounts for 25%-35% of the total cost [4]. Perhaps, the kiln that achieves the highest thermal efficiency is the vertical shaft kiln developed in China. This vertical shaft kiln functions exactly the same as the horizontal tunnel kiln but the bricks move vertically downward. The natural draft obtained by this setting eliminates the power required by the exhaust blower. The vertical shaft kiln is suitable only for that country which has ample supply of labor. Nepal and Pakistan are now adopting the vertical shaft kiln [5].

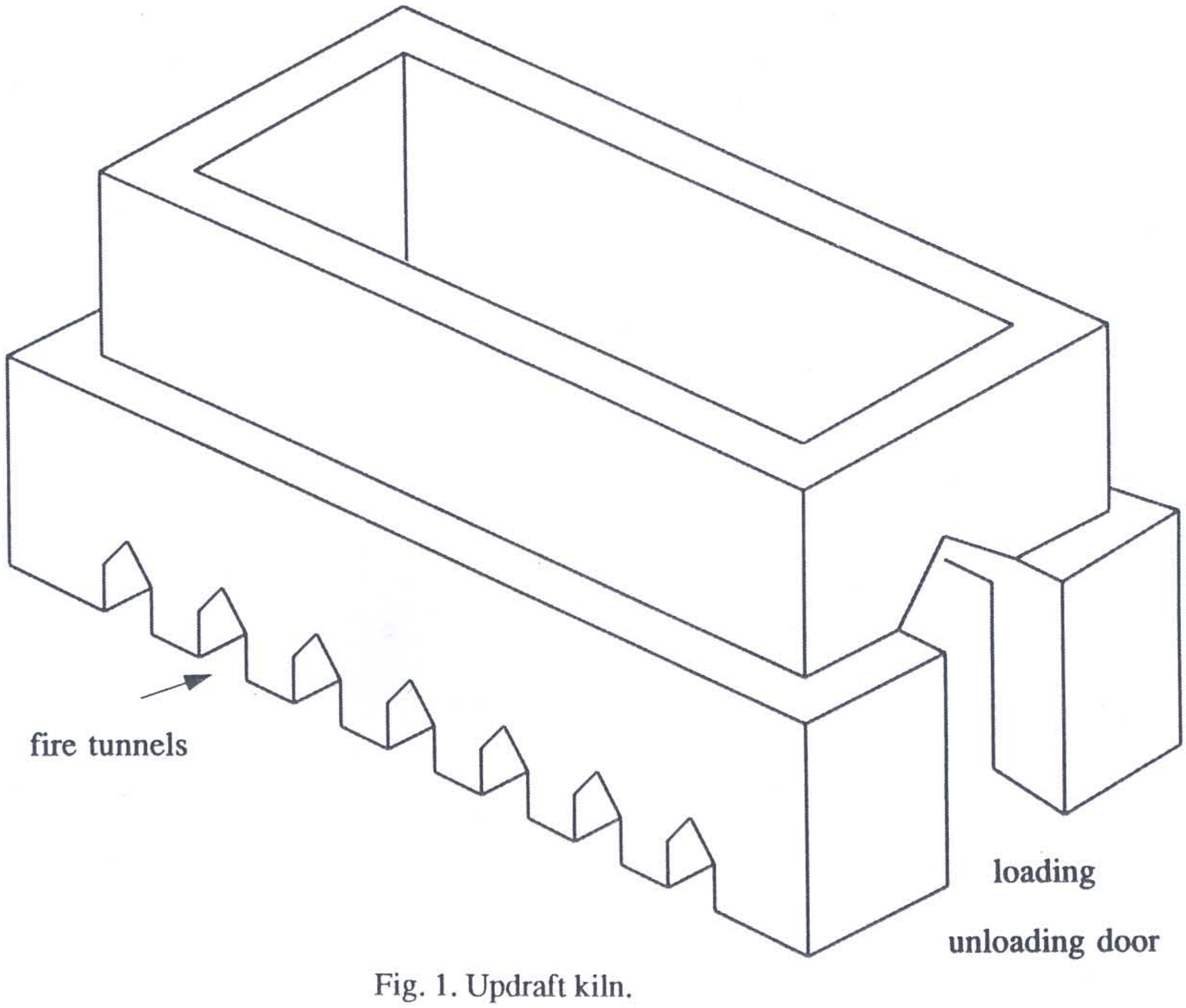


Fig. 1. Updraft kiln.

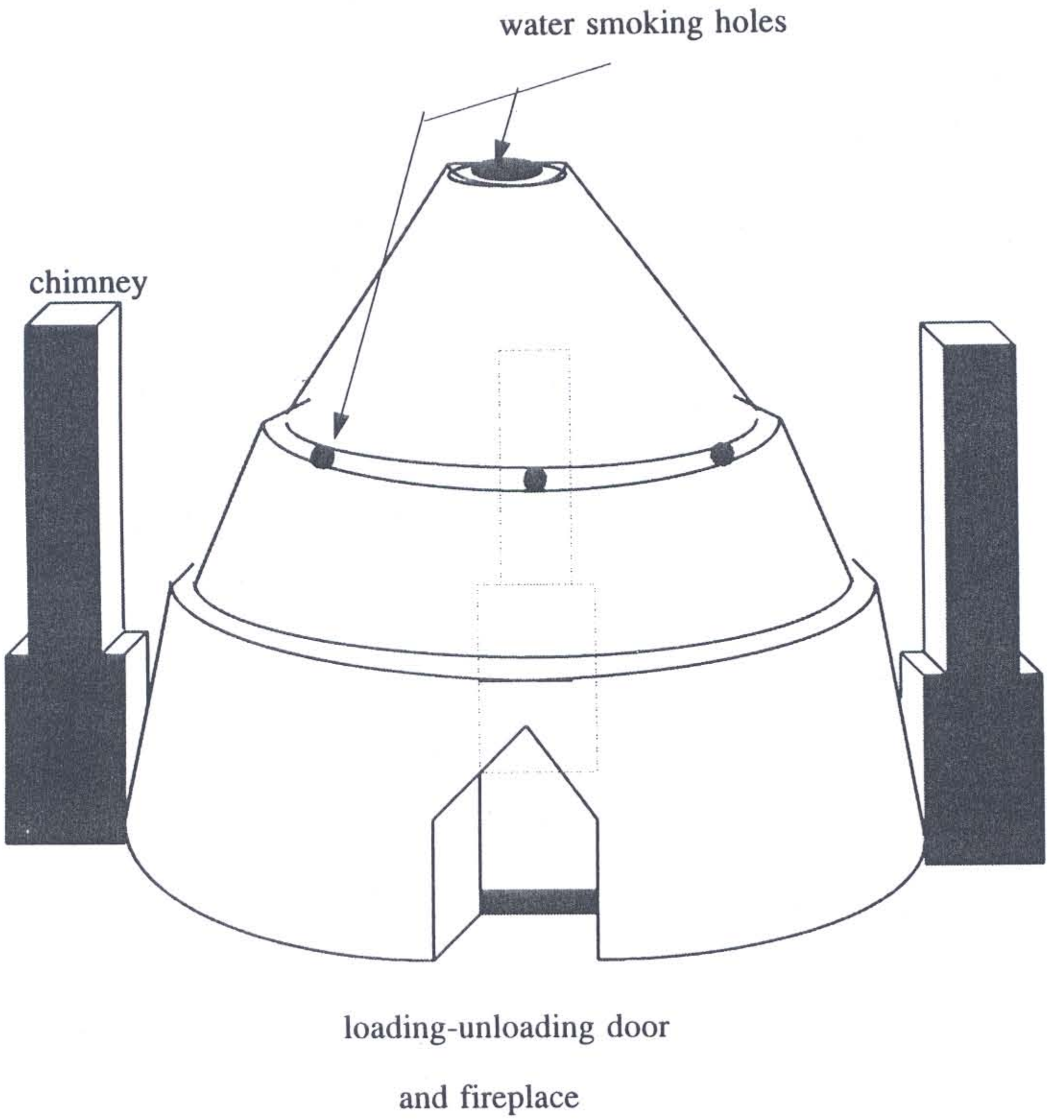


Fig. 2. Dowmward kiln.

## 3. EFFECTS OF FIRING TIME AND TEMPERATURE ON BRICK PROPERTIES AND ENERGY CONSUMPTION

### 3.1 The Experiment

Firing time and temperature are the two key factors attributing to the energy usage. Unnecessarily prolonged firing time and too high temperature will eventually consume more energy. Minimum firing temperature and shortest firing time do not only reduce energy but also increase the productivity of the factory. In this experiment, the effects of firing time and temperature on the brick properties and energy consumption were investigated. The properties under investigation are weight loss, compression strength and water absorption.

Ready mixed clay was obtained from a brick factory in Hat Yai, Southern Thailand. The test specimens were 220 cubes of 32 x 32 x 32 mm$^3$ formed from a single lot of clay to assure the identical composition throughout the experiments. The cubes were exposed to 100 °C for 48 hours to remove the free water in the clay. Each cube was marked and weighted (Shimudzu electronic balance, Model

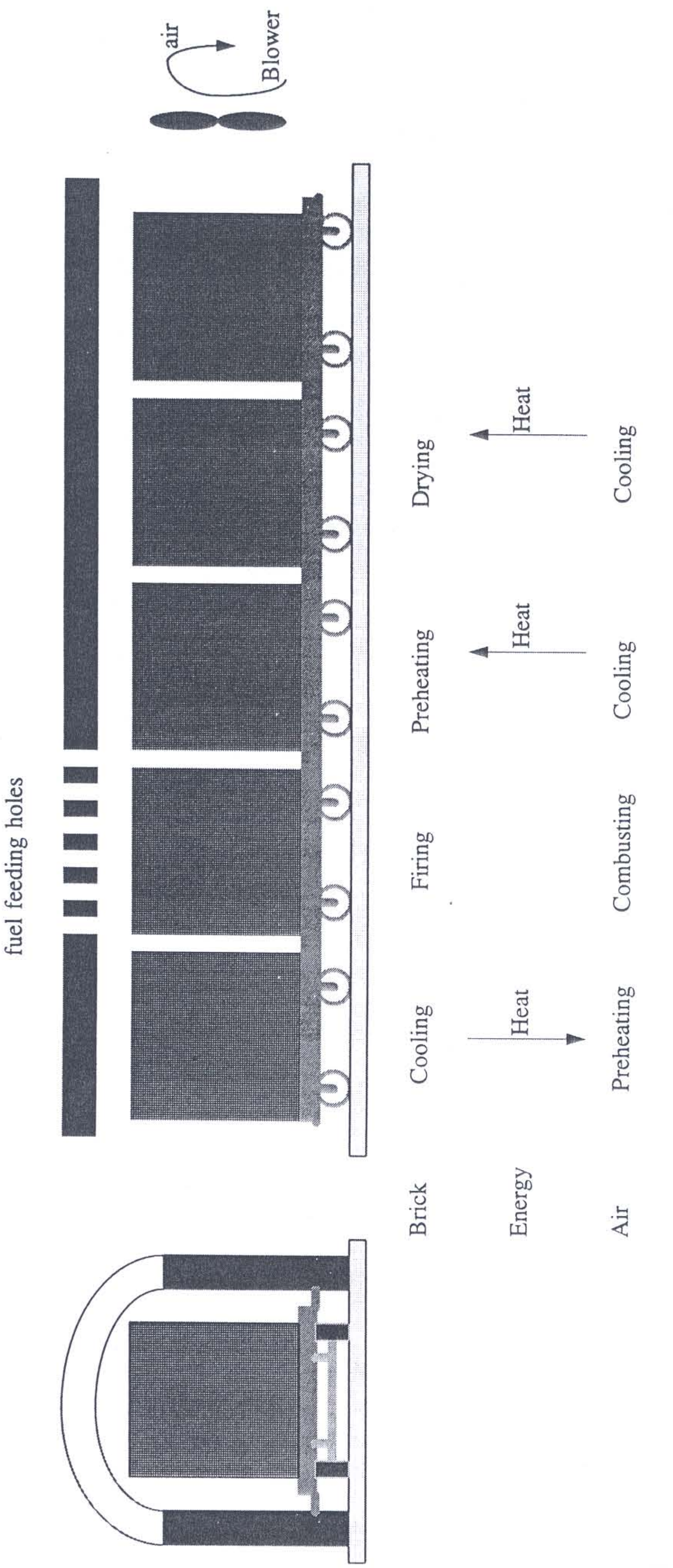


Fig. 3 Continuous kiln.

Libror EB-3200H, resolution 0.01 g.) before firing in an electric furnace (Neyo Model 2-1350A). Thirty five (35) specimens were fired at 600°C, 700 °C and 800°C of which 5 specimens were drawn from the furnace every 60 minutes for its property examination. Only 20 specimens were fired at 900°C where the sampling interval was 120 minutes. The firing time of every temperature was, therefore, 7 hours. The effects of the firing time and temperature were determined from the weight loss, compressive strength and water absorption. The specific energy required in the clay-to-brick (CB) transformation was calculated based on an energy balance basis.

Preliminary examinations found that the brick fired at 550°C, although turning reddish because of the oxidation of ferrous silicate [6], was swollen and decomposed when soaked in water. At this temperature, dehydroxylation takes place and carbonaceous organic matter starts to burn off [7]. However, the firing temperature of 550°C is lower than the quartz inversion temperature of silica. Silica, which is a common constituent of the quartz component of the clay used for making bricks, changes its crystal form at 573 °C [7]. Therefore, the minimum temperature for brick firing in this study is 600°C. The effects of firing time and temperature on the mechanical properties of brick are given in Table 1.

Table 1. Effects of firing time and temperature on mechanical properties.

| Mechanical Properties | Firing temp. | Firing time | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|
| | | Hr. 1 | Hr. 2 | Hr. 3 | Hr. 4 | Hr. 5 | Hr. 6 | Hr. 7 | |
| Weight Loss (%) | 600 | 4.19 | 4.11 | 4.38 | 4.44 | 4.42 | 4.32 | 4.22 | 4.30 |
| | 700 | 4.67 | 4.59 | 4.73 | 4.62 | 4.61 | 4.78 | 4.68 | 4.66 |
| | 800 | 4.89 | 4.89 | 4.93 | 4.81 | 4.79 | 4.88 | 4.89 | 4.87 |
| | 900 | 4.92 | - | 4.95 | - | 4.94 | - | 4.94 | 4.94 |
| Compressive strength* ($kg/cm^2$) | 600 | 92.8 | 92.3 | 93.6 | 90.2 | 90.3 | 98.4 | 99.0 | 93.8 |
| | 700 | 103.4 | 105.7 | 110.4 | 111.2 | 109.6 | 109.8 | 112.0 | 108.96 |
| | 800 | 143.3 | 140.5 | 147.4 | 146.1 | 141.5 | 142.5 | 142.1 | 143.34 |
| | 900 | 181.2 | - | 178.1 | - | 182.6 | - | 185.4 | 181.82 |
| Water absorption (%) | 600 | 17.21 | 16.91 | 17.20 | 17.41 | 17.14 | 17.08 | 16.50 | 17.06 |
| | 700 | 17.34 | 17.30 | 17.37 | 17.45 | 17.41 | 17.32 | 17.40 | 17.37 |
| | 800 | 17.54 | 17.48 | 17.77 | 17.87 | 17.98 | 18.01 | 17.94 | 17.81 |
| | 900 | 17.56 | - | 17.61 | - | 17.64 | - | 17.49 | 17.57 |

* 1 $kg/cm^2$ = 42.74 Pa

### 3.2 Weight Loss

Firing time (1-7 hours) is the time after the furnace temperature reached the set values (600°C-900°C). It became obvious that weight loss, which is caused by dehydroxylation and carbonaceous matter burnt off, is not time dependent. Weight loss increases as the firing temperature increases. Weight losses of bricks fired at 600°C and 900°C were 4.30% and 4.94 %, respectively.

### 3.3 Compressive Strength

Compressive strength was determined by a conventional compression rig. The cross head speed was set in accordance with the ASTM C67-73 guidelines. The compression load was determined by a standard ring. Like the weight loss, the firing time plays no role in the compressive strength (Table 1). The variations at different firing times were patternless and might be the result of inclusions in the clay, such as sand and organic matter. The strength of the brick is remarkably improved by firing at high temperature. Bricks fired at 700°C, 800°C and 900°C had strengths of 116%, 153% and 194% of those fired at 600°C, respectively. It must be borne in mind that figures in Table 1 are the property of a solid-cubical brick and cannot be compared with the strength of an ordinary brick.

### 3.4 Water Absorption

The percentage of water absorption was determined by submersing the brick in water for 24 hours (Thai Industrial Standard. (TIS) 153-2533). The results expressed in percent of dry basis are included in Table 1 and demonstrate that the firing time does not affect the water absorption property. It is of interest to note that there appears to be no effect of firing temperature (in the range of 600°C-900°C) on the water absorption property.

Since the brick in this study is a non-load-bearing brick, water absorption is the only mechanical property specified by the TIS 153-2533. It is believed that this applies to many developing countries where surface finishing by mortar is a common practice. Water absorption ability of the brick affects the surface finishing of the brick-laid wall. Excessive water absorption causes the finishing mortar to lose its water rapidly (to the brick) and hinders the proper chemical reaction of the cement. Too low water absorption, which normally is due to vitrification at temperature over 900°C, introduces difficulties in holding mortar to the brick. TIS 153-2533 sets three classes of non-load-bearing brick based on water absorption. Brick classes A, B and C should have a maximal (average from 5 samples) water absorption of 10%, 14% and 20%, respectively. As it is shown in Table 1, both firing time and temperature have no effect on the water absorption property, water absorption will depend solely on the raw material preparation.

Since mechanical properties do not depend on the firing time, it is possible to conclude that the clay transforms to brick at the moment its temperature reaches the firing temperature.

### 3.5 Clay-to-Brick (CB) Transformation Energy

Any study aiming to reduce energy consumption has to begin with realizing a knowledge of the minimum energy required by the process. The minimum energy can be determined either by a theoretical approach of energy require for the chemical structure and phase transformations or an experimental approach. The theoretical approach involves detailed chemical analyses and assumptions which may not lead to the correct figure. Experiments based on energy balance which directly gives the answer was carried out in this study.

Thin sheets of clay, the moisture of which was removed at 100°C, were fired in an electric furnace. Furnace temperature and energy (calibrated SEIMENS kWh meter) were recorded continuously until it reached the set firing temperature (600°C, 700°C, 800°C or 900°C). Since the sheets of clay were only 10 mm thick, it was assumed that the temperature difference between the furnace and the innermost part of the clay sheets is negligible. In other words, the clay completely transformed to brick at the moment the temperature of the furnace reached the set value. Total energy, which is the sum of CB transformation energy and energy lost to surroundings, was obtained from kWh meter readings. The energy lost to the surroundings was determined by running the brick-filled furnace at various temperatures ranging from 100°C to 900°C in increments of 25°C. After the steady state (at each temperature) was reached, the energy consumed within sixty minutes was recorded and regarded as an one-hour energy loss (to surroundings) at that particular furnace temperature. The rate of energy loss at every temperature expressed in terms of kJ/s was subsequently calculated. Knowing the time-temperature profile recorded previously in the brick firing experiment, the associated energy loss profile could be evaluated. The energy required in CB transformation is the difference between the total energy consumed and total energy lost.

The specific energy of bricks fired at 600°C, 700°C, 800°C and 900°C are 569 kJ/kg, 706 kJ/kg,

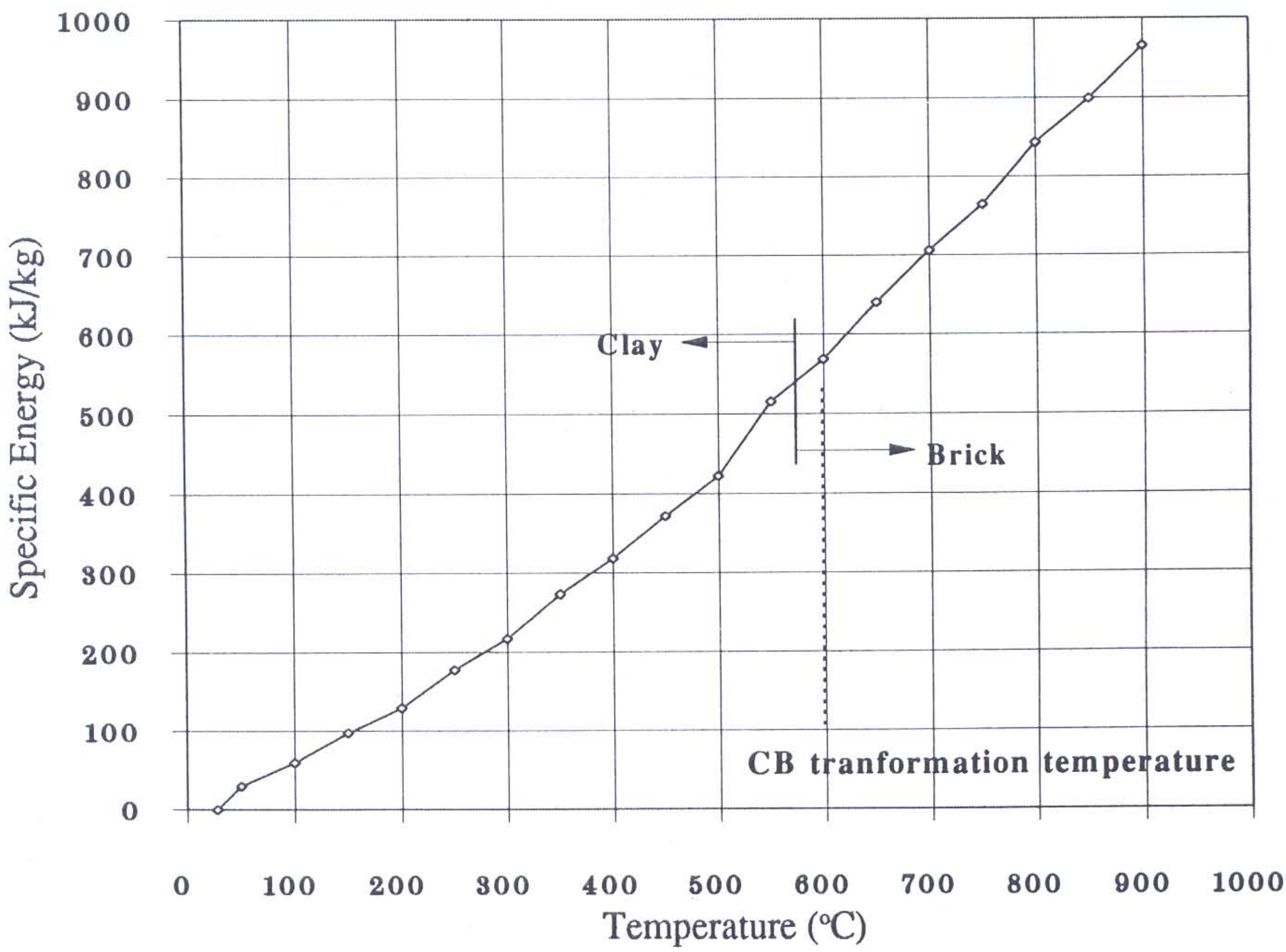


Fig. 4. The relation of the specific energy (Based on mass of fire brick) and firing temperature.

843 kJ/kg and 966 kJ/kg, respectively. These figures are well below those obtained from the actual firing in industrial kiln, which is generally quoted at 3000 kJ/kg [5,7]. Fig.2, which is the average result of two experiments, gives the relation of the specific energy (based on mass of fired brick) and firing temperature. The two experiments were undertaken with different masses of brick and it was found that their results deviated from the average value by less than 10%. A brick fired at higher temperature requires higher energy. This can be explained by the heat capacity of the brick and extra energy is needed for removing the volatile matter (a brick fired at higher temperature has a higher weight loss) and the decomposition of carbonates and sulfides [6]. The specific heat of a brick at 600°C-900°C can be derived from Fig. 4 as 1.34 kJ/kg °C. This figure is relative high compared to the value of 0.92 kJ/kg °C - 1.0 kJ/kg °C generally quoted in some references [8, 9]. The difference may be caused by the inaccuracy in this experiment which is not the standard method for determining the specific heat of substance. Furthermore, the calculation was based on energy measured during the firing process which involves other processes (e.g., removing volatile matter) apart from heating.

The structure of the chemical compounds of the clay and the bricks fired at 550°C, 600°C, 700°C, 800°C and 900°C was studied by an X-ray diffractometer [4]. The results show no discrepancy if the firing temperature is 600°C and above which confirms that the minimum CB transformation temperature is 600°C (or specifically 573°C). However, in practice the kiln temperature must be well above 600°C to create a sufficient temperature gradient in the clay so that heat can transfer into the inner part of the clay. Furthermore, energy is both time and temperature dependent. Firing bricks at low temperature does not necessarily consume less energy since the firing time is longer (in order to obtain at least 600°C in any part of the brick). Therefore, the minimum energy in practice must be a compromise of time and temperature.

## 4. AREA TO MASS RATIO EFFECTS

It is concluded that the minimum energy required in brick firing is obtained by optimizing the firing time and temperature. Kiln temperature plays an important role in the rate of heat transfer into the clay. High kiln temperature, although fuel consumption rate is high, eventually shortens the firing time and may consume less energy. The firing time also depends on the thickness and surface allowable for the heat to transfer. Therefore, hollow bricks with different hole dimensions should require different energy and time. A brick with bigger holes is lighter, hence consumes less energy per brick. The firing time will also be shorter because the large surface area enhances the heat transfer. The hollow brick in this study was a four-rectangular-hole brick typically produced in Southern Thailand. The holes are formed in axial directions in an array of 2x2. The external dimension of the brick is 69x86x195 $mm^3$. The hole dimension was varied and the variable parameter in the study was defined as "area to mass" (AM) ratio. Seven sizes of holes with dimensions of 11x18 $mm^2$, 12.5x19.5 $mm^2$, 14x21 $mm^2$, 15.5x22.5 $mm^2$, 17x24 $mm^2$, 18.5x25.5 $mm^2$, and 20x27 $mm^2$ were used in this experiment. The corresponding AM ratios are 75.0 $mm^2/g$, 80.3 $mm^2/g$, 86.5 $mm^2/g$, 92.8 $mm^2/g$, 97.3 $mm^2/g$, 105.2 $mm^2/g$ and 109.8 $mm^2/g$. Bricks of every AM ratio were produced from the same batch of clay and placed together in the kiln to ensure the identical raw material and firing conditions.

The bricks were tested for compressive strength, water absorption and three-point bending. The compression test was performed on an area of 69x195 $mm^2$, at the direction that the bricks are laid on each other in the wall construction. The bricks were faced with mortar to compensate distortion, if any, and hence eliminated the bending load. Water absorption was tested in accordance with the TIS 152-2533. Ten and five samples were used in the compression and water absorption tests, respectively. The

Table 2. Effect of area-to-mass ratio

| Brick designation | AM ratio[1] (mm²/g) | Mass (kg/brick) | Compressive strength[2] (kg/cm²) | Water absorption[3] (%) | Bending load[4] (kg) | Allowable stack height (m) |
|---|---|---|---|---|---|---|
| A | 75.0 | 1.51 | 34.93 | 20.00 | 490(12) | 267 |
| B | 80.3 | 1.49 | 33.98 | 21.23 | 486(12) | 264 |
| C | 86.5 | 1.39 | 26.53 | 20.42 | 462(13) | 221 |
| D | 92.8 | 1.33 | 21.18 | 20.08 | na | 193 |
| E | 97.3 | 1.30 | 20.33 | 20.09 | na | 181 |
| F | 105.2 | 1.27 | 16.57 | 20.06 | 364(16) | 151 |
| G | 109.8 | 1.20 | 15.01 | 19.95 | na | 145 |

1 Average of 3 samples

2 Average of 10 samples

3 Average of 5 samples

4 Figures in brackects are number of samples

three-point bending experiment was performed on the weakest direction (minimum moment of inertia of area, breadth=86 mm) which is also the direction the bricks are stacked together during handling. The span of the roller supports was 175 mm. The breaking load of the three-point bending test indicates the susceptibility to breakage during handling. The effects of the AM ratios on the brick properties are shown in Table 2.

As expected, the water absorption capability does not depend on the AM ratio. The percentage of absorption, which was about 20%, was slightly higher than those in Table 1. This discrepancy is a result of different raw material preparation. The cube samples in Table 1 were manually formed and believed to be less porous than those machine formed bricks in Table 2. Furthermore, a different moisture content of clay during the forming results in a different green brick density which, at a certain degree, reflects the porosity of the fired brick. Water absorption capability of the brick is partly attributed to the porosity of the brick.

Bricks with higher AM ratio (lighter) undoubtedly withstand a lower compressive load. Compressive strengths of the lowest and the highest AM ratio bricks are 34.93 kg/cm² ( 0.82 Pa) and 15.01 kg/cm² (0.35 Pa), respectively. The corresponding masses are 1.51 kg/brick and 1.20 kg/brick. The lightest brick, although it weighs almost 80% of the heaviest one, can carry a load of only 43% of the heaviest brick. As the load bearing capacity varies non linearly with the mass of the hollow brick, the allowable heights of walls constructed from the different AM ratio bricks are not in the same magnitude as shown in Table 2. However, the wall constructed from the weakest brick can be as high as 140 m before the bottommost brick collapses due to the weight of the wall. Generally, the wall height is less than 5 m otherwise a supporting beam is needed.

Results of the three-point bending test were obtained for four AM ratios only because of insufficient samples of the other AM ratios. A light brick is prone to handling damage as indicated by low failure load in the three-point bending test. However, the failure load was not sensitive to the hole area. Brick F had a hole area 2.1 times of that for brick A while the failure load of A was 1.3 times of that for brick F. It must be noted that the handling damage of brick is mainly caused by impact and most of the cases are associated with precracks in the brick. Precracks are induced by many factors such as thermal stress, expansion during quartz inversion, excessive drying rate during water smoking and unequal expansion of inclusion and clay. Cracks can be developed even during the green brick forming (because of insufficient moisture in the clay) as was observed in some factory visits. Observations at some construction sites in Hat Yai revealed that the amount of handling damage did not relate to the hole size. In some cases, cracks were easily seen in bricks that have four small round holes (about 8 mm diameter) and consequently a high portion of handling damage was also observed. The main functions of the holes in the brick are to ease the moisture to escape, reduce the level of moisture gradient, hence the internal stress and crack formation and prevent distortion during drying. All these functions are enhanced by the big holes. In other words, a lower AM ratio brick (small hole) is not always better in terms of strength and handling damage. It is likely that the preparation of raw material plays an important part in the mechanical properties of the brick. In one case of factory visits in Northern Thailand, 20% of green bricks were split into two halves during sun drying simply because the clay was too fat (high proportion of the clay particle). Another 30% were broken after firing and unloading from the kiln . Adding a few percent of non-shrinking materials such as fine sand, grog or rice husk ash reduced the shrinkage and has solved the problem.

Because the failure load in the three-point bending test is not so sensitive to the hole dimension, brick can be produced with a high AM ratio (less raw material and energy) and still maintains strength by improving the raw material preparation, e.g., proper moisture during forming, reduce shrinkage, proper water soaking and kneading. These simple techniques are already well known among experienced brickmakers.

## 5. GENERAL DISCUSSION

The brick firing technique in developing countries was passed from generation to generation. Because brick making is traditionally a small industry in rural area where biomass fuel is plentiful, the struggle for improvement is not realized. Many questions have never been asked. These include the questions for the optimum capacity of the kiln, the proper setting pattern of the bricks in the kiln, the brick dimension and the firing temperature and time. Big updraft kilns which inefficiently consume firewood for a 7 day operation are commonly seen in these countries.

As the wood must be either conserved or converted to value-added products, the brick industry is now facing an energy crisis. Although other agricultural residues such as saw dust and oil palm shell are available (in Thailand) at no or very low cost, they cannot be a substitute for wood unless the furnace is modified to cope with the small size fuels [10]. A sophisticated furnace such as the fluidized bed may not be appropriate for this kind of small family-based industry. However, the lack of energy-related basic knowledge has hindered the improvement of the brick making process in all aspects. Perhaps, the only development in order to efficiently use the energy is the implementation of the tunnel kiln (continuous process). However, as the scale of the brick making industry in developing countries is very small, the tunnel kiln is not appropriate. Findings from this study should be used to lay a foundation for the design and operation of an energy-efficient batch-type brick kiln suitable for the rural area. Because the minimum temperature for brick formation is 600°C and the firing time has no effect on the mechanical properties, the kiln and the brick setting should be designed so that the temperature is not necessarily too high but uniformly distributed. This will save energy and shorten firing time. Waste heat must be recovered but batch operation must be maintained. Machine-formed hollow brick should replace the manually-formed solid brick. Results from this study have generated an innovative concept of design and operation of the brick kiln. The concept was tested by computer simulation and presented in Part 2. The kiln is being constructed and experiments to verify the simulation will be carried out and reported in due course.

## 6. CONCLUSION

A study aiming to gain a basic knowledge for energy saving in brick firing was carried out. It was found that the weight loss and compressive strength of brick fired at 600°C - 900°C increased with the firing temperature. Firing time showed unnoticeable effects on these two properties. Water absorption, which is the only property specified by TIS, is independent on both firing time and temperature. Specific energy for brick formation is in the range of 570 kJ/kg -1000 kJ/kg brick depending on the firing temperature. This finding implies that the present practice in brick firing, which takes 5-7 days and consumes 3000 kJ/kg brick, can be improved to save energy by reducing the firing time. That is, the kiln should be small and the bricks are set in a way to facilitate the uniform temperature distribution. Waste heat recovery or usage should also be incorporated in the process. The hollow brick is recommended, because higher surface area will enhance heat to transfer into the innermost part of the brick and, consequently, shorten the firing time.

## 6. ACKNOWLEDGMENT

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