ENERGY EFFICIENCY OF NON-FACE BRICK PRODUCTION WITH PARTICULAR REFERENCE TO THE DRYING PROCESS.

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I, Herbert William Garnet de la Hunt submit this thesis in fulfilment of the requirements for the degree of Master of Science in Applied Science. I claim that this is my original work and that it has not been submitted in this or in a similar form for a degree at any University.

ABSTRACT

Energy inefficiencies are at present a characteristic of the Heavy Clay Industry throughout the world. In the Western Cape there has been a marked trend towards the use of unsophisticated plant for the manufacture of non-face plaster bricks since the nineteen sixties. At present all non-face plaster bricks are fired in clamps and only a few factories use dryers.

Hollow ware, rather than solid bricks find favour in South America, Asia and Europe, with the exceptions of the United Kingdom and the Netherlands,(the Netherlands use the soft mud process which does not lend itself to hollow ware production). However in South Africa, in spite of potential energy and clay saving, the number of hollow block factories, has shrunk in the past 30 years. The only move towards hollow ware, has been the perforation, of face bricks. In the Western Cape no factories perforate their non-face bricks. The reduced production and cartage costs, could be passed on to the builder. Other advantages for low-cost housing are easier bricklaying, as well the aesthetic appeal of clay for semi-face finishes. Of considerable concern, to the Heavy Clay Industry is the fact that the energy and clay saving, as well as the reduced cartage cost, allows the clay hollow block to be competitive against cement, it's major rival in the field of "affordable housing". The hollow block, although larger, can be lighter than the solid brick, and has the further advantages of less units per square metre "in the wall", as well as good insulating properties.

To produce hollow ware in the Western Cape, without major plant changes, it was necessary to test the possibility of firing hollow ware in clamps. This was achieved for the conventional non-face brick size and the maxi brick, both made with transverse holes.

The purpose of this study was to provide an efficient method of drying bricks, particularly for factories which were drying in the open air. The hollow ware possibility widened the scope of the study and a dryer was designed to dry both hollow ware and solid bricks. A constraint on the dryer design was the basic premise that the dryer would ultimately form part of an integrated dryer/kiln system.

Open air drying in the Western Cape, while requiring no additional heat or electrical energy, does use forklifts, which use diesel and are expensive. The open air drying process has a high waste component and is weather dependent. Heavy losses have been experienced, not only during the autum and spring, but often even in the middle of summer, due to unseasonal downpours. Arguably the main area of concern, to the producer, is the inefficient use of plant and labour during the winter months. The costs, to the producer, of the open air drying process were established.

The literature survey dealt with the basic principles and problems of drying heavy clay products, as well as innovations and engineering problems in the field of drying.

Initial tests were done on a test unit, large enough to simulate plant conditions. From the results of these tests, the work covered in the literature, as well as past practical plant experience, sufficient information was available to build a prototype plant dryer.

The prototype dryer was constructed to dry units standing "one-high, soldier". With this setting, and the proposed airflow, it is possible to treat each unit in exactly the same manner as it's neighbour. In this way it is possible to obtain results comparable to those obtained under laboratory conditions and achieve fast drying times. Fast drying implies a relatively small dryer with minimum heat losses, as well as having good control. The "One-high" configuration lends itself to simple setting and off-loading mechanisms.

An objective of this study was to minimise the capital investment. The value of the waste saving, on open air drying, over two years, was regarded as an arbitary amount to aim for, as the cost of the dryer. In fact the dryer was built at below the capital cost of the forklifts which were eliminated by changing the drying method. Pallets were eliminated, as was the need for setting labour.

Fast drying of the order of 1-3 hours implies that the dryer is, in a sense, an extension of the extrusion process. The dryer can be switched on and off with the extruder, but, what is more important is the fact that a plant which normally operates only on day shift, can be operated on a 24 hour basis without the need to build extra drying facilities. This latter point is of considerable importance in building boom periods.

Clamps do not generate recoverable waste heat for drying. Phase two of this project will be to design the kiln which is compatiable, in concept, with the dryer. The proposed kiln will operate with less specific energy than clamps and generate the heat required to dry the bricks.

In conclusion, the study leaves the fine tuning of the dryer for energy efficiency, still to be completed. In spite of this the dryer satisfies all the proposed conceptual criteria. It will be able to operate on the waste hot air from the kiln. If the kiln can operate at the level of the best commercial kilns at present available, and yet be built for a capital amount of the same order as the dryer, then an attractive alternative to clamp firing will have been found. Because the recoverable heat from the kiln is available, irrespective of the drying process, there will be no specific energy drying cost, the same situation that applies with open air drying, but, with none of it's attendent problems.

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NOMENCLATURE

A_{qe}	Area cross-section (using variables l_y and l_z)	cm^2
A	Drying surface area of setting	cm^2
A_q	X^n of drying air circl^n between bricks (initial)	cm^2
c	Specific heat of a body	kJ/kg °C
cp	Specific heat of gas	kJ/kg °C
Cp	Specific heat at constant pressure	kJ/kg °C
D	Diffusion constant.	--
h	Heat transfer coefficient	$kJ\ m^{-2}\ K^{-1}$
h*	Heat content or enthalpy of the moist air.	kJ/kg dry air
l	Specific characteristic length for the heat flow.	cm
l*	Specific length	cm
l_x, l_y, l_z	Space between green brick and it's neighbour.	cm
n_x	Position of green brick in direction of flow.	--
Rb	Crack width	mm
t	Temperature of moist air.	°C
Tu'	Transfer units	--
u	Velocity	ms^{-1}
v	Flow rate	ms^{-1}
w	Flow rate	ms^{-1}
w_e	Air velocity	ms^{-1}
x	Water vapour content of the moist air.	g/kg dry air
X	Drying rate	$\%h^{-1}$
X_o	max. drying rate	$\%h^{-1}$

Greek letters

α	Heat transfer coefficient	kJ m^{-2} K^{-1}
β	Mass transfer coefficient	$kgm^{-2}K^{-1}$
β^*	The dry air component in kg/m^3 moist air.	kg/m^3 moist air
$\Delta h/\Delta x$	Heat consumption	kJ/kg water
φ	Relative humidity i	%
λ	Coefficient of thermal conductivity	$kJ/m^2/m$
θ_2	Dimensionless waste air	--
θ^*	Kinematic viscosity	m^2/s
θ	Temperature	^oC
ρ	Density	kg/m^3

NUMBERS

Nusselt number	**Nu**
Prandtl number	**Pr**
Reynolds number	**Re**
Stanton Number	**St**

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GLOSSARY

The large majority of the items listed below were taken from a glossary compiled by H. Schmidt of the Brick and Tile Institute Essen. Published in the ZI International, August 1978

Arris
The sharp junction where two sides of a brick join.

Backing Bricks
See NFP's

Bigot Curve
The curve obtained by means of a Barelattograph which records the course of the linear drying shrinkage in relation to the moisture extraction rate.

Building Bricks
See NFP's

Blade
A blade of bricks usually applies to a narrow stack of bricks on a kiln car.

Clamp
An early, though still widely used, method of firing bricks. It consists essentially of a dense setting of bricks and fuel which is ignited and left to burn. Some fuel (usually coke breeze or high carbon ash) is put into the brick mix but a further quantity goes into the setting itself.

Climate
Denotes quite straightforwardly the "sensible" environmental conditions as applied to the drying of clay products, the variables are:

- temperature
- relative humidity

- air velocity
- pressure
- gas composition

the last two factors are relatively unimportant in the heavy clay industry.

Climate - (immediate)
Denotes the climate prevailing in the immediate vicinity of the individual product, which ultimately determines the drying curve.

Climate - ("dryer")
Denotes the conditions recorded through probes e.g. temperature and relative humidity

Commons
See NFP's

Condensation point
see: Dewpoint

Convection drying
Heat transfer to the ware to be dried by means of an air or gas flow.

Contact drying
The drying of the ware by contact with heated surfaces in which the heat transfer is effected by conductivity.

Dewpoint
Temperature at which moisture-laden waste gases condense. Every gas-water vapour mixture has - according to the water vapour pressure - a specific dewpoint temperature at which the vapour begins to condense, e.g. flue gases.
water-vapour dewpoint approx. **25-40°C**
sulphuric acid dewpoint approx. **130-180°C**

Dry bulb thermometer
Component of the psychrometer which indicates the air temperature.

See also: Wet bulb thermometer.

Dry strength, Dry bending strength (or green strength)

Bending strength of cylindrical or trapaziodal green unfired rods in a transverse test, expressed in N/mm^2.

Drying, liability to failure

Ratio of linear drying shrinkage in per cent to the time at which initial cracking occurs in minutes. The cracking time is determined by means of a drying test (see: Ziegeleitechniches Jarbuch 1958, p.142 et seq.).

Drying sections

Characteristic sections of the "Drying diagram for clay bodies" according to Bourry.

Section 1: The volume decrease (shrinkage) corresponding to the volume of water released.

Section 2: Progress in the shrinkage and pore formation.

Section 3: End of shrinkage. The pore volume increases as a result of further moisture release.

see also: Inflection point.

Drying sensitivity

Liability of a material to cracking especially frequent in the case of fat, fine-grained clays.

The drying sensitivity is related to the mixing water requirement, the moisture conductivity coefficient and the strength properties of the clay.

Drying shrinkage, linear.

Length change in the ware on drying, in relation to the length of the moist green product, in per cent.

see also : Firing shrinkage
Total shrinkage (overall shrinkage)
Shrinkage,total (shrinkage overall)

Engineering Systems

The term " engineering systems" as used in this paper, refers to the mechanical engineering and mechanical handling aspects of the brick and hollow-ware manufacturing process.

Enslin value

Ratio of the max. volume of water absorbed in cm^3 to the weight of the clay in g, expressed as a percentage. Value for the hydraulic or water bonding and hence the plasticity.

Enthalpy

Heat content of a gas, e.g. kJ/kg, or to be more precise; the product $\mathbf{c.\theta}$ or $\mathbf{c_p.\theta}$ as enthalpy h (at constant pressure).

c = specific heat of a body
c_p = specific heat of gas
θ = temperature

Final firing temperature (Finishing temperature)

The maximum permissible final firing temperature is the temperature at which, under prescribed conditions (e.g. heating up rate 5K/min; applied load 0.05N/mm^2; without soak time), a softening of 0.5% is ascertained (electric firing). There are additives which increase the maximum permissible final firing temperature (e.g. refractory clay, sand, lime) or lower it (fluxes or raw materials with flux constituents).

The maximum permissible final firing temperature is therefore of particular interest because a high degree of firing is aimed at in order to obtain adequate compressive strength and frost resistance. In the high temperature range, owing to proliferation of partial fusion areas or to the extension of the fusion phases proportionately, when the maximum permissible final firing temperature is exceeded, the bricks or other products become deformed by softening. It is therefore normally adviseable to restrict firing to this temperature as an absolute maximum.

Practical experience has shown that, providing allowance is made for a holding time at peak temperature (to achieve an even temperature) and allowing for other types of kiln atmosphere, the temperature of the green ware in the kiln, depending on the clay used, can be the same or lower than the "max. permissible firing temperature" (on occasions by as much as 40^{o} C).

Firing Curve, optimum

The optimum firing curve is represented by the shortest temperature-time schedule possible for the firing of raw clay products (solid brick. perforated bricks, clay roofing tiles etc.) consistent with freedom from cracking and deformation.

Firing shrinkage, linear

Change in the length of ware on firing, taken on the length of the dried, unfired product in per cent. The firing shrinkage may be regarded as the external characteristic feature of the sintering process.

see also: Drying shrinkage
Total overall shrinkage

Green Bricks

Bricks which are either still wet with extruded moisture or dry unfired bricks.

Heat capacity, specific

Volume of heat required to increase the temperature of, e.g. 1kg water by 1^{o}C.

Examples:

Water: c = 4.187 kJ/kg K = 1 kcal/kg^{o}C

Air: c_p = 1.00 kJ/kg K = 0.24 kcal/kg^{o}C

Ceramic material: **c** ˜ 0.92 kJ/kg K = 0.22 kcal/kg^{o}C

Heat consumption of dryers

This is calculated according to the formula:

$$Q = \frac{\text{given heat volume/h}}{\text{water volume evaporated/h}} \text{ (kJ/kg)}$$

Heat evaporation

Heat volume required to convert a volume of liquid to a gaseous state without additional heating.

Humidity, maximum

Water vapour volume which can be absorbed by 1m^3 max. air (saturation value).

Humidity, relative

see: Relative humidity

Hygrometer (hair hygrometer)

Instrument for measuring relative humidity in per cent.

Inflection point

An inflection point or breakpoint in the Bigot Curve (denoting linear drying shrinkage in relation to water extraction) which is found to occur in practice between the 1st and 2nd drying phases. The point at which the transition occurs from a moist to a dry surface (the "leather hard" transition). The point at which this is found provides an indication of the moisture volumes expelled respectively in the first and second drying phases, i.e. up to the inflection point and after the inflection point.

Laths

Usually strips of wood or hollow metal sections (~ 40mm x 40mm), 1 metre or longer which are used to support bricks or blocks in a dryer.

Mixing (or tempering) water required

Water required for making a workable mix to a specific, uniform consistency. It is this which confers the plasticity on the clay body, so that products can be moulded, e.g. into complex shapes. Ratio of wet minus dry weight to dry weight of a body in per cent.

Moisture absolute

Volume of water in grammes which is contained in $1m^3$ dry air.

Moisture content

Ratio between the moisture minus the dry weight, to the moist weight, of a clay body in per cent. The mixing water required or the water content on the other hand are taken on the dry substance.
see also: Water content
Mixing (or tempering) water required

Moisture readsorbtion

The resumption of the absorbtion by the unfired products after the drying process. If this amounts to more than 2% considerable losses in strength may occur.

NFP's

Non face plaster bricks, also called, stock bricks, backing bricks, building bricks, plaster bricks, commons or R.O.K's (run of kiln). These are bricks made for use as backing material behind a facing, and having no claim to attractive appearance. Frequently covered with rendering in external walls, and when used internally are normally plastered.

Nusselt number Nu

Dimensionless characteristic number "t" used to describe the heat transfer occuring between solid bodies and gases or liquids.

$$\mathbf{Nu} = \frac{\alpha . l}{\lambda}$$

Where

α = heat transmission coefficient

l = specific characteristic length for the heat flow.

λ = coefficient of thermal conductivity

Optimum drying curve

The time-temperature curve of the max. permissible moisture extraction rate in the respective drying phases for the drying of green clay products in a setting adapted to the natural conditions in the shortest possible time consistent with freedom from cracking and deformation.

Plaster Bricks

see NFP's

Prandtl number Pr

Characteristic number applied to the heat transfer in a flow state.

Pr for airflow: 0.72

Psychrometric difference

Difference in temperature between the wet and dry bulb themometer (hygrometer) determined by means of a psychrometer.

Quartz inversion

Volume expansion or volume contraction in the temperature range **575°C**

- Preheating range:

Conversion of the free quartz from β into α type, characterised by volume expansion.

- Cooling range:

Conversion of the free residual quartz from the α to the β type, characterised by volume contraction.

Relative humidity
Ratio of absolute to maximum humidity in per cent.

Reynolds number Re
Characteristic number in fluid mechanics for hydronamic reactions taking place under the influence of inertia and friction.

$$\mathbf{Re} = \frac{v.l^*}{\theta^*}$$

where
v = flow rate
l* = specific length
θ* = kinematic viscosity

R.O.K's
See NFP's.

Shrinkage, total (overall shrinkage)
Change in length during drying and firing, taken on the length of the moist, green product in per cent. If however one wishes to determine the extruder die volume, the total length change (in mm) during drying and firing should be taken on the volume of the end product.

Sintering
Beginning of partial fusion or increase proportionately of molten phases which, in the case of low-lime clay bodies, is accompanied externally by firing shrinkage and internally by a reduction in the open pore volume, i.e. by visible changes which may thus be traced. Lime-rich clays on the other hand at the normal industrial temperature range display hardly any shrinkage (from time to time some expansion) and they usually have a remarkably large open pore volume.

Sintering interval
The sintering interval is the term applied to the temperature span between the commencement of sintering
(i.e. vitrification) and the maximum permissible final firing temperature.
see also: Final firing temperature, max. permissible.

Soldier
A term used in the setting of bricks which describes the position where the largest dimension of the brick is set vertically.

Sorption isotherms
Curves produced by plotting the relationship of the moisture content to the relative humidity prevailing immediately above the material (e.g. dried green products or fired bricks) at constant temperature.

Stanton Number.

$$St = \frac{h}{\rho \; Cp \; u}$$

where h = heat transfer coefficient
ρ = density
Cp = specific heat at constant pressure
u = velocity

Stock Bricks
See NFP's

Stoichiometric Ratio
The chemically correct ratio of fuel to air. i.e. a mixture capable of perfect combustion, with no unused fuel or air.

Systems engineering
A scientific "problem solving" system, which designs complex processes in a lucid manner, and seeks to obtain factually relevant, realizable and operational solutions on the basis of analysis of a system in it's totality.

Total shrinkage (or overall shrinkage)
see : Shrinkage, total

Waste Gas
Gaseous residual products of the combustion process e.g.of oil and gas firing, which are emitted from the process.

Water content
Ratio of wet minus dry weight to the dry weight of a clay body in per cent. The moisture content on the other hand is taken on the moist substance.
see also: Moisture content

Water of crystallization, release
By water of crystallization is meant the chemically bonded water which is integrally contained in the crystals. Clay minerals release their water of crystallization in various firing temperature ranges (theoretical):

Koalinite	390° - 600°C
montmorillonite	450° - 650° or 850°C
illite	400° - e.g. 900°C
mica-type minerals	450° - 650°C

Wet bulb thermometer
Component of the psychrometer. Water is evaporated at the wet bulb thermometer(or hygrometer), the bulb of which is wrapped in a damp swab, wick, stocking etc. The greater the evaporation, the dryer the air. The thermometer is cooled simultaneously as a result of the evaporation. The difference in temperature between the wet and dry bulb thermometer is known as the psychrometric difference.

CHAPTER ONE

INTRODUCTION

1.1 SUMMARY

No justification whatsoever is required to investigate the possibility of energy conservation in any application, but because the Structural or Heavy Clay Industry is amongst the larger consumers of energy in industry, in South Africa, and also because it has a poor record of energy usage, it's case deserves urgent attention.

Two additional points are of distinct interest to the heavy clay manufacturer.

- Costs are of prime concern in any manufacturing process.
- The heavy clay industry has an additional challenge in that cement products, it's formidable rival in the masonry application, use less specific energy per cubic metre of end product "in the wall", than clay masonry products.

In the actual manufacturing of heavy clay products, the drying and firing sub-systems are the largest consumers of energy and it was with the above points in mind that an investigation was carried out to explore the production process and establish the characteristics of an ideal dryer suited to the solid brick and hollow-ware section of this industry.

1.2 THE ENERGY CONSUMPTION OF THE HEAVY CLAY INDUSTRY IN THE BROADER SOUTH AFRICAN CONTEXT.

40% of the total energy requirements of South Africa was accounted for by the industrial sector in 1972[1].

The structural clay industry was also identified as being energy intensive and Koch is quoted as stating that it accounted for roughly 2% of the energy used in the manufacturing sector.

Huggett[2] confirmed that the structural clay industry was amongst the five industrial sub-groups which accounted for approximately two-thirds of the energy consumed in the industrial sector. He quotes the 1979 Census as stating that the same five sectors accounted for 41% of the total industrial energy consumption by cost. He further established that the energy consumption of the brickmaking industry was 17×10^6 Gigajoules per annum. This seems low, and De Villiers[3] estimates that the energy consumption of the strutural clay industry, in 1991, was 51PJ per annum.

1.3 REASONS FOR ATTEMPTING TO IMPROVE THE HEAVY CLAY INDUSTRY'S ENERGY USAGE.

Energy Utilisation in S.A.[1] reports that the efficiency of energy conversion within the structural clay industry is 31% and reports Chamber and Tunnel dryers as operating at 42% & 43% efficiency excluding the efficiency of the air heaters. This order of efficiency still applies at the present time and many South African dryers are of simple design with a straight "in and out" hot air flow without reheating or any attempt at recirculation.

In 1980 Lingl[4] expressed the belief that specific energy saving in the industry was possible but to date, in spite of the potential cost saving, relatively little is being done in this regard by the individual brick maker or the industry.

Considering the above, and personal experience over the past 25 years, investigation into the use and abuse of energy in the structural clay industry is justified.

Further concern is appropriate considering that the energy used in this industry, apart from open-air drying, is derived entirely from non-renewable reserves, and Williams[5] concludes that it is imperative that we mimimise our dependence on these resources.

Huggett[2] identifies a possible 13% total energy input saving in the clay brick industry in South Africa but agrees that the U.K. projections of a 50% saving could well apply to the South African industry. A 50% potential fuel, and 25% specific power requirement saving, in the industry, is corroboratted by Handle[6].

Apart from the cost saving and the moral implications of energy conservation, the Structural Clay Industry has an incentive to maintain it's market share against masonry cement products. Bennett[1], Williams[5] and Pels Leusden quoted by Handle[7] all make unfavourable comparisons in favour of concrete as against clay as with respect to the specific production energy consumed per cubic metre in the wall. Handle[7] quotes Pels Leusden's article "Energiesparen beim Trocken und Brennen" in which he says that, at the time of writing, "21 litres of oil are needed for $1m^2$ of a 30cm thick brick wall. For $1m^2$ of a concrete wall with the same statical properties, 8 litres are needed. In addition 5 litres oil/m^2 are needed for equal insulation." Implying a 40% difference in favour of concrete in the European situation and possibly an even worse comparison in South Africa, where the insulation factor could be considered to be less important. Bucher and Stahl[8] confirm that energy costs for concrete, gysum and calcium silicate products are considerably lower than for heavy clayware. With the increased awareness of the need for responsibilty for energy conservation, this comparison could become a serious marketing factor in favour of cement and other substitute products, as against clay products; in spite of the fact that clay wall units are arguably superior to cement in many aspects.

1.3.1 The advantages of hollow ware and perforated bricks as against the conventional solid brick.

There is yet another aspect concerning clay building materials in South Africa. Some 95% of these units made in South Africa are solid according to Williams[5]. It is imperative that, not only the energy in the manufacturing process be reduced, but also that the mass of clay being processed be reduced, clay being a non-renewable resource. The production of hollow-ware, instead of solids, will make a major contribution to both of these requirements.

Further advantages to be derived from changing to hollow-ware production are as follows:

- The drying and firing of the ware, which, because of it's hollow nature, has thinner walls for drying and heat penetration, can then be speeded up with attendent energy saving.
- The specific mass of the product is less and therefore cartage costs and the energy used in transport is relatively less.
- The hollow-ware also has the added advantage of being a better insulator, when built into the wall, than solid bricks.
- Perforated bricks are, of course, lighter than solid bricks and hollow clay ware is relatively lighter than cement blocks. This facilitates the mason's job and therefore leads to increased productivity.

It is common practice in Europe and South America to use hollow-ware and in fact solid bricks are an anachronism.

1.4 THE BRICK AND HOLLOW-WARE PRODUCTION SYSTEM.

Heavy Clay Products are mass produced and the manufacturing unit can reasonably be divided into five sub-systems.

1.4.1 Claywinning

This is the process where clay is mined, usually by open-cast methods, and is brought to the factory by elevator scaper or dump truck.

1.4.2 Clay preparation

The particle size of the mined clay is reduced so that there is an optimum range of fractions to facilitate compaction, during pressing or extrusion, and to achieve a maximum particle size suited to the type and quality of product to be produced. This particle size distribution is achieved by the crushing, grinding and possibly the screening of the material. Traditionally there are two methods of working clay prior to the shaping of the ware, these are the "wet grinding" and "dry grinding" processes. The former is appropriate when the mined clay is wet, with a moisture content as high as 35% in Europe, but it is often considered by some to be good practice to add water to dry clay before grinding in a Wet Pan and/or Refinning Rolls. In the dry process the clay is reduced to the desired particle size before any water is added to achieve the correct moisture content for the shaping process.

1.4.3 The shaping of the ware.

The method of shaping determines the amount of water that will be mixed with the clay. The hand-moulding of bricks which is often simulated by "soft-mud" machines - typical of Holland - is often termed the full plastic method and, depending on the clay, can use up to 30% of water by mass on the dry basis.

Extruded, or wire cut bricks, are made with a wide range of moisture contents, with the "Stiff" extrusion process, which was developed in the U.S.A., requiring the least water. Consequently because the water content is at it's lowest with stiff-extrusion,the plasticity of the extruded material is also less, and therefore more kW are required by the extruder. The energy economics of this method are well argued by Steele.(9)

Bricks are also shaped by pressing and are generally classified again by the moisture content at the time of shaping. These range on a continuum from "stiff plastic" to "dry pressed", the latter method being defended by Spengler(10). Dry pressing, in effect, obviates the drying process because the only water present is that absorbed by the clay, due to it's properties as a desiccant. The process terms are not definitive and names like semi-dry, semi-plastic and dry press are used loosely often depending on the locality in which the bricks are made.

Hollow-ware in the form of floor blocks, wall blocks and bricks with holes in them are shaped by extrusion, often requiring complex dies. The forming of these products depends, to a very large extent, on the plastic properties of the clay/water mixture and cannot be made with too stiff an extrusion or dry pressing.

1.4.4 The drying process.

This is essentially the process of removing water from the green ware, necessary in some cases to give sufficient rigidity to the body to enable the articles to be set upon one another in the kiln, but the function of drying is primarily to remove water, which would interfere with the firing process. According to Stahl in Bender and Handle[11], depending on the type of clay, the water to be removed from the drying charge could be between 10-40% by mass. In the drying of ceramic materials, the dried green ware, depending on the type of clay, it's geometrical configuration and mode of kiln operation, should have a residual moisture of 0.5 - 6%, prior to entering the kiln. Clay is a desiccant and it would only be advantageous to dry the ware completely if it went directly into the kiln. Moisture content of the ware becomes more critical if the ware is fired in a "fast-firing" kiln after drying. Thater[12] claims that the drying of green products is one of the most difficult problems facing the brickmaker. Drying accentuates mistakes which have been made in the preparation, extrusion or the die operation, and it is often, only during drying, that they become apparent. The dryer is in fact an index of some hidden defects in the product. On the other hand, while faults cannot be remedied in the dryer, controlled drying can minimise the effects of laminations in extrusion, for example.

1.4.5 The firing of clay ware.

During the firing process the last of the mechanical moisture is driven off. For the most part the chemical or combined water is removed before 650^{o} C but the last vestiges of chemically combined water may only leave the ware at about 900^{o} C. Oxidation and reduction reactions take place, and depending on the kiln atmosphere, with the impurities in the clay. Carbonaceous matter, if present, is burnt out and other chemical reactions occur depending on the composition of the clay. There are often both endothermic and exothermic reactions during the firing process. The physical β to α quartz change at around 575° C can account for a 2% change by volume. There is a phase change due to vitrification at higher temperatures. At the lower end of the vitrification temperature range, which is usually at about 900° C, sintering starts, assisted by the fluxes in the clay. The strength of the body increases due to glass formation and physical bonding. The upper vitrification level is the point when the required strength and water absorbtion level for the product is reached. Vitrification can be allowed to continue up to the point where distortion of the body, under it's own weight, takes place. When referring to temperature in the firing sub-system it must be remembered that it is the temperature-time to which the charge is subjected (to permit the necessary vitrification to take place), that is of importance in determining the upper firing temperatures, when firing ceramic products.

Boke, who has written a chapter on the firing of heavy clay products in Bender and Handle(13), describes firing as - "the final ceramic engineering process in the manufacture of structural products, confering bonding, making it insoluble to water, giving it a measure of resistance to chemical attack and the required compressive strength and colour."

1.5 THE REASON FOR SELECTING THE DRYING SUB-SYSTEM FOR INVESTIGATION.

In Huggett's(2) survey of the South African heavy clay industry, he reports that on average 95% of the total energy consumed was used in the drying and firing sub-systems. This order of magnitude (90%) is corroborated by figures generated from a table by Walley and West(14) which refers to building bricks in the U.K.**{APPENDIX 1.1}**

In Bender and Handle(15), further support for this statement is provided in a table, by Bender and Smalzried, for energy consumption figures for European clay building materials.**{APPENDIX 1.2}** These figures identify the sub-systems of drying and firing as being of particular interest from an energy conservation point of view.

Traditionally, in the heavy clay industry, these two sub-systems have been closely linked insomuch that heat is often recovered during the cooling phase of the firing cycle to assist, and often provide, the entire heat requirements for drying. This recovered heat is erroneously referred to as "waste heat" and is often regarded as free. Williams(5) quotes the Corobrik tunnel kiln at Driefontein as providing 38.8% of the nett producer output to the dryer. The trend in the industry should be to design efficient kilns which generate no "waste heat".

An acceptable deviation from this aim is the counter travel kiln developed by Rudolf Riedel in 1979 which is now commercially available from Fritz Werner GmbH. In June 1991 five kilns were in operation. In 1985 when assessing the counter travel kiln Riedel, Jeschar and Wagner(16) explain that the only exhaust was that taken from the firing zone which was high temperature and low volume. These exhaust gases were passed through a heat exchanger to provide all the hot air for drying the ware (containing 25% moisture). The total fuel consumption was low at 1529kJ/kg fired ware, for a red-firing lime-free clay. They suggest perhaps in the order of 419kJ/kg, was required for firing with the dryer being possibly more efficient than the 1257kJ/kg fired ware, quoted.

This kiln is claimed to operate efficiently and provides clean hot air for the dryer. The dryer must not be designed to use the available hot air but rather for maximum efficiency. Should it not be possible to reduce the heat derived from the kiln, to match the needs of an efficient dryer, then the additional heat can be used for other purposes.

While the firing process is a basic requirement of modern ceramic structural clay products, this is not the case with the drying process. This is illustrated by the fact that dry pressing is an acceptable, although not popular, method of shaping bricks, even though it finds wide application in the refractory industry. Work has been done by DiLiddo(17) and Brownell(18) on Hot Pressing and this process has been developed to a pilot plant level(19).

These latter two methods obviate the need to add, and subsequently remove, water but they do ignore the fundamental characteristic of clay, namely, that it is a material which forms a plastic mouldable body when mixed with water.

Whatever the merits of the above arguments with regard to the forming of bricks, hollow-ware does rely on being moulded in the softer plastic state and so, because of the premise of versatility of products, in this investigation, (the need to produce solid and hollow-ware) and the fact that the vast majority of bricks produced in South Africa are by extrusion, it was necessary to plan for the addition and removal of water. This means that a dryer is necessary.

Stiff-extrusion is in a sense a compromise which uses more specific energy for shaping, consequently reducing the amount of water needed to extrude a satisfactory brick. Steele[20] argues that while the specific energy for stiff-extrusion is greater than for a softer extrusion method, the overall energy requirements in the clay preparation and extrusion are much the same due to the fact that less preparation is required for the stiffer extrusion. It is a method which allows the use of less plastic clays thus widening the range of raw materials suitable for making bricks. It is finding increasing application in South Africa but of course is not economical where the moisture content of the mined clay exceeds that required for stiff extrusion, as this would necessitate pre-drying the clay before extrusion.

If a choice has to be made to investigate either the drying or the firing sub-system, independently, such investigation has to consider the systems engineering needs of both sub-systems so that ultimately an integrated system can be developed.

The decision to examine the drying sub-system first was, in a sense, arbitary. Handle [21] claims that, according to investigations made in West Germany, German brick factories need an average of 5900 kJ/kg water to be removed for drying and 1300 kJ/kg fired brick for firing. Assumed that 20% on the fired weight is water to be removed, then the ratio is, 1300 : 1180 :: Firing : Drying. In the same survey the electrical energy consumed amounted to approximately 1500 kJ/kg fired ware. In July 1992, Junge[22] quotes a range of 3428 kJ/kg to 5017 kJ/kg water evaporated, comparing a range of operative dryers. Theoretically it requires 1000 kJ/kg to raise clay to 1000^{o} C and it requires 2400 kJ/kg to evaporate water. In the process being considered a maximum of 20% water is required for mixing, and so, per thousand bricks, theoretically less energy is used in drying than in firing. On the other hand there are dryers recorded in Bender[11] which consume specfic energy at the rate of 12 600 kJ/kg of evaporated water.

The following quotation by Thater [23] perhaps reflects a need for looking at the drying process, " Many brickmakers are unfortunately unaware that most dryers have a higher heat consumption than their kilns."

The deciding factor, which influenced the decision to investigate drying before firing, was the fact that, in the Western Cape, in particular, many factories do not make bricks in winter because of very slow drying and possible rain damage. The brick industry required a dryer with a low specific energy consumption, of low capital cost, which was environment friendly and had low maintenance costs. Brick factories which do not have dryers and therefore use open air drying, usually fire their bricks in clamp kilns.

Clamps can be fired through the winter and so the acquisition of a dryer would allow production to be maintained throughout the year. This would result in more cost effective factories and would mean that the regular shortage of commom building bricks which has been experienced each winter, for the past 20 years, would no longer be a problem.

1.6 The situation with regard to the manufacture of NFPs, in the Western Cape, over the past 30 years.

The following paragraph indicates an interesting phenomenon which has taken place in the NFP industry, in the Western Cape, that is, a dramatic trend to unsophisticated production practices.

All of the NFP bricks, that is, all bricks other than face bricks, and some pavers, which are manufactured in the Western Cape, at present, are fired in clamps. This was not always the case, in fact, up to the early 1970's a large number, indeed the majority, of non-facing bricks were made in kilns. The following factories are quoted to support this statement. Hare's Brickfields in Mowbray used a coal fired tunnel kiln. Rochester in Salt River, Hume Pipe and Glenboig in Parow, Blakes Bricks Ltd in Koelenhof and Gordon's Bay, used Hoffmann Kilns. Brick and Clay used a Buhrer Kiln in Bellville and built two Bock (underground Hoffmanns) at Georgedale. Blakes Bricks, although they had built it for another purpose, fired common building bricks in their new (1965) Morando Tunnel kiln at Killarney, near Milnerton. All of the above factories, with the exception of the Blake's factory at Gordon's Bay, had separate dryers. Not one of these kilns is in operation today.

It is not within the scope of this paper to consider the reasons why NFPs are no longer fired in kilns but rather to establish which energy efficient and economical route should be taken for the NFP section of the Heavy Clay Industry.

1.7 A FINAL CONSIDERATION.

The industrialist is faced with an obligation to the shareholders to provide the best possible return on their investment. Jointly, with the shareholders, he has a responsibility to the environment and for the prudent use of non-renewable resources. In South Africa the provision of job opportunities is an important consideration. All these factors were carefully weighed in the investigation.

CHAPTER TWO

LITERATURE SURVEY

2.1 SUMMARY

The survey of the literature relevant to the drying of bricks and hollow-ware is set out in a sequence which considers the subject as a whole, with brief reference to the theory of drying heavy clay products and then goes on to look at various methods of reducing the water needed for extrusion and pressing. Subsequently reference is made to the methods of water removal and energy sources which have been investigated.

Ventilation as a major aspect of convection drying is reported on and this is followed by reference to energy conservation techniques which have been researched.

Papers dealing with induced air flow, in convection drying, with paricular reference to experimental work on air flow are examined and evaluated. Various aspects of heat recovery and fuel efficiency are considered. The Systems Engineering approach to dryer design is considered as well as practical suggestions on evaluating and controlling the drying cycle.

2.2 THE DRYING OF HEAVY CLAY PRODUCTS - AN OVERVIEW.

A comprehensive discussion of drying is given by Stahl(24) who covers terms and basic processes, the bases of calculation, clay drying, dryers in the ceramic industry and concludes with a section on operating problems. He refers (pp 335) to the work of Thater, done in 1974, which he says indicates good prospects for fast drying, of even the more sensitive German clays. Junge(25) considers the problems of drying heavy clay products and their solution with reference to the properties of the clay body. He states that the "free water" is almost completely expelled in brick and tile dryers down to a residual amount of 5%. and that, "Permanently bonded water only escapes at the beginning of the firing process and - depending on the type of bonding - extends well into the preheating zone. These processes should in fact be regarded as part of the drying process. "The processes occuring in the green ware during drying are referred to, and he notes the problems caused by the migration of salts and fine particles, to the surface in the initial drying phase, and the reaction which can take place if the atmosphere in the the dryer contains acid forming components. This is a potential problem, as it is standard practice to have "internal" or "direct firing", as distinct from some form of heat exchanger, to heat the air.(Ref. Hans Lingl GmbH & Co. KG). The three phases of convection drying are discussed as he regards convection drying as the basic way of drying bricks. The first phase is critical because of the possibility of drying cracks and Junge maintains that it extends over a relatively long period which should be longer than the period over which the essential shrinkage processes occur. It is essentially a time of heat and material transfer and is best achieved with high air velocities so as to minimise the drying time. The second phase is that period during which the water is evaporated from the interior pores of the ware and it is during this phase that bricks are usually removed from the dryer. The third phase was referred to above and also involves a risk of cracking. Techniques for the prevention of drying cracks and deformation are discussed, he refers to manipulating the cooling limit temperature through temperature and humidity control, and also suggests heating the brick before it enters the dryer by hot extrusion techniques and microwave preheating but, en passant, rejects microwave drying as too expensive. He continues his paper with a discussion on energy consumption for the drying of bricks and tiles (which will be referred to later in this chapter) and concludes with reference to dryers in the clay industry. In this latter section (pp 18) he claims that dryers, other than continuous and chamber dryers, are at present of no particular importance in the brick and tile industry. He considers the chamber dryer to be more versatile than continuous dryers. He refers to "jet dryers" which can be integrated into the production line, these are capable of rapid drying schedules, appear to require low investment and suggests that resumption of the development work carried out on these would be desireable. He concludes his paper with the observation that in Germany there are exceptional cases where bricks are so hard, when extruded, that they can be stacked directly onto the tunnel kiln car. This has been standard practice in the U.S.A. and South Africa for many years.

Fischer[26] maintains that despite the rich accumulation of empirical data over the decades, the drying of bricks remains a very difficult technical process. Of particular interest to this investigation is his statement that, "The faster the drying process, the better the exploitation of the dryer air's heat content". He remarks, inter alia, that drying sensitivity is influenced by factors such as the unfavourable body shape, shaping induced internal stress and unfavourable drying behaviour of the body composition. The damage in drying results from a coincidence of adverse processing conditions such as air temperature, the setting pattern and unfavourable body properties. He warns that because clay has a broad spectrum of capillary widths and the fact that a large amount of water is bonded by coulomb forces and polarization forces onto the clay particles, the simple concepts of the wetting of solids by liquids do not apply. His paper is a good source of reference to the work done in the area of the bonding of water in plastic clay-base bodies. He deals with surface layers and says that about four layers of water molecules about 1,25nm are tightly bonded and are virtually part of the solid. The water shows an increasing "viscosity" as it gets closer and closer to this bonded layer and he quotes H.Scholze that in plastic clays the influence of particle surface polarization forces can produce layers of 30 molecules or 10nm. Information on the mechanism of bonding is provided by sorption isotherms, i.e curves in which the equilibrium moisture is plotted as a function of the partial pressure of water vapour. These are used as a tool for characterising wares to be dried, and also can be evaluated to yield information on the bonding energies that hold the water. Tables of "Moisture stress" as a measure of the bonding energy of water on solid surfaces are given. These indicate that decreasing the relative humidity results in the breaking of increasingly strong bonds. He comments on shrinkage and shrinkage stress and refers to the division of the gaging water into "shrinkage moisture" or "coating water" which is the easily removable capillary water and the strongly bonded "residual moisture" or "interstitial water".

In a section on the transport of water to the surface of the shaped body he deals with the first phase of drying which is characterised by a coherent film of water on the surface of the body. He maintains that the drying rate depends on the temperature and humidity of the air which determine the temperature at the surface of the ware (the cooling boundary temperature). Obviously the greater the (psychometric) difference between the two temperatures the greater will be the heat transfer which determines the rate of evaporation. As an aside he explains that the cracks in ware resting on pallets are due to heat conducted to the ware which is not dissipated because no water can be evaporated from the ware at the point of contact.

This phase presupposes that the capillary system remains functional for as long as possible as this is the most favourable phase of drying but obviously a high degree of capillary conductivity is a prerequisite and this characteristic is material dependent. He discusses the work done on moisture conductivity and highlights the fact that the coefficient of moisture conduction is influenced by the viscosity of water which increases significantly with a rise in temperature. This phenomenon can be exploited in practice by applying high temperatures in, or before, the first phase of drying.

Information on drying behaviour and the transition between the first and second drying phases can be obtained by plotting the weight change of the specimen with respect to time and then calculating the drying rate by way of the moisture. Futher it is pointed out that all that is known about outer and inner drying conditions applies to the individual shaped body and that this is hardly applicable to drying conditions in a large volume dryer.

Of particular interest is the section entitled "Raw material and body properties with influence on drying behaviour" which is the classic approach, covering specific surface and its bearing on sorption/capillary behaviour, cation exchange capacity, and the type of clay minerals. The permeability and the cation capacity (the flocculation state of the clay) are correlated and a practical application is to use flocculants to improve the permeabilty of the body and thus effect the drying behaviour. This section is concluded with reference to the addition of coarse or nonplastic materials and their effect on drying. He makes the statement that "Undoubtedly, sorption behaviour is the crucial criterion with respect to the drying behaviour of any clay."

Balint and Matrai(27) state that approximately 25 factors infuence the quality and drying period of bricks. In 1984 75% of Hungarian brick and tile works were using artificial methods of drying.

Ratzenberger(28) stresses that the properties evident in preparation, shaping, drying and firing are consequent on the primary properties of the material but concludes that even though a mathematical formula for the relationship between drying sensitivity and mineral content has been established much work has to be done to explain these relationships. In 1990 Ratzenberger(29) reported on a method of determining drying sensitivity introduced at the Institut fur Bau- und Grobkeramik, Weimar.

For completeness reference is made to Moravek(30) who has presented a mathematical argument to prove that differences in drying sensitivity can be based mainly upon the differences in the rheological properties of the bodies.

2.3 METHODS OF REDUCING THE AMOUNT OF WATER WHICH IS ADDED FOR EXTRUSION AND ADDITIVES WHICH FACILITATE EXTRUSION AND REDUCE DRYING SENSITIVITY OF THE WARE.

Perforating the product and stiff extrusion are possibly the major contributors to the reduction of the amount of water that would normally have to be expelled from a dryer. Steele(31) argues the overall energy advantage in preparation, mixing and extrusion of using the stiff extrusion method as against more preparation and mixing with lower kilowatts for softer extrusion. This leaves the reduced water load in the dryer as a bonus. Steele and Steele(32) list the advantages of stiff extrusion, inter alia, because of high pressure, a more even moisture distribution, greater chip resistance in all stages of production, the possibilty of using marginally plastic clays and of course a product which can be handled and more readily stacked.

Snauwert and Somers[33] refer to steam injection's ability to increase production capacity and Clews[34] claims that the introduction of steam in the extrusion process not only eases extrusion but reduces the amount of tempering water added.

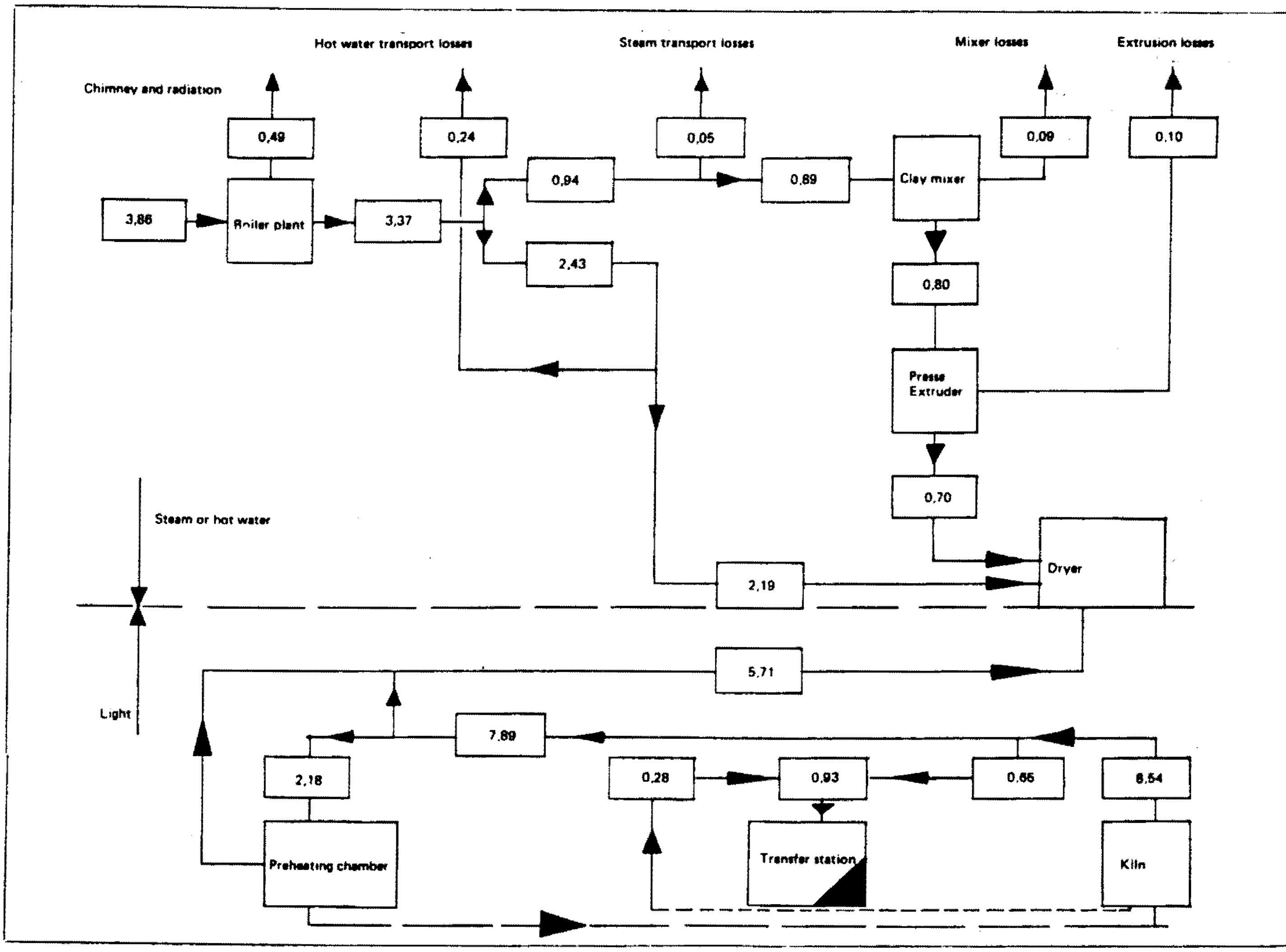
Steele in a customer communication, written on the 21st June 1979, argues for the addition of hot water, as against steam for practical production reasons and claims that reducing the surface tension of the water assists penetration which in some clays may increase plasticity which, he maintains, is not really necessary unless extrusion is through a die with a multiplicity of very small cores.

Anwyl[35], referring to the Hereford Brick Plant in Hereford Texas back in 1965, reports that "hot water in the pug mill is a real aid in successfully extruding the Permian Clays"

An obvious conclusion is that all indications are to the advantages of adding steam or hot water before extrusion. Plant tests need to be done to establish whether the temperature of the extruded column can be raised sufficiently with hot water or low pressure steam. The efficiency of heating in the mixer will have to be determined and be evaluated against the initial heating in the first phase of drying which would be necessary were the ware not heated before entering the dryer.

An indication of expected losses due to steam raising, as well as hot water transport and in the mixer and extruder can be gauged from a schematic diagram [**FIGURE 1**] provided in a paper by De Leeuw[36]. He reports the energy saving achieved by replacing hot-water heaters with gas burners in a chamber dryer. The numerical data in **Figure 1** represents heat volumes in MJ/hr.

Junge[37], reporting on experiments being carried out by the Brick and Tile Research Institute at Essen states that the aim was to reduce the risk of drying cracks by raising the temperature of the ware. The risk of drying cracks occur in the first phase when the temperature of the ware is equal to the so-called "cooling limit temperature" which is dependent on the temperature and moisture of the dryer air. Raising the temperature increases the moisture conductivity of the material resulting in a greater uniformity of the moisture and shrinkage within the material. The test have been successful but no further quantitative information is provided in the report.



A schematic diagram of energy flow excluding the kiln. (In MJ/h)

FIGURE 1

Mihailescu, Alexenco, Cocis, Bartic & Carlugea[38] report on the effect of four plastifiers (plasticizers) on Romanian clays and report 20 - 25%

moisture reduction. Schmidt-Reinholtz[39] selects additives which have given positive results in lowering natural drying sensitivity.

The addition of additives has not been regarded necesary with South African clays used for brickmaking and hollow-ware. In recent years Calcium-ligno-sulphonate, which is sold commercially under the trade name of "Additive A", has been available locally. It's addition reduces the water required to achieve the necessary plasticity and it is claimed that it gives greater green strength to the product. It is possibly a reflection of the attitude of the heavy clay industry in South Africa that it is not in common use.

Hilker, referred to by Rieseler[40], suggests that drying properties can be improved by the use of "opening" additives. In addition to improving drying they can reduce shrinkage, and reduce the overall water requirement. He also draws attention to the fact that the additives also affect shaping properties as well as the dimensional stability and green strength of the products. He refers to the balance of the grain size distribution of these additives and the original body for optimum results. Ash, and to a lesser extent, grog and sand find application in South African brickmaking plants.

2.4 ALTERNATIVES TO CONVECTION DRYING - RADIATION AND VACUUM.

Mori[41] reports the results of laboratory tests and industrial trials on ceramic articles using infra-red and microwave radiation and describes the physical considerations involved. That the two radiation methods are superior to convection drying is indisputable from the results quoted both from the rapidity of drying and energy costs viewpoints. The disadvantages of infrared radiation is the dependence of the heat transmitted on the square of the distance between the body and the radiation source and the consequence which this has for the uneven heating of irregular bodies, as well as the possible different positioning of different pieces. These problems are absent with the application of microwave heating and because ceramic materials are transparent to microwaves, the magnetic field can be uniformly absorbed by the water in the body. He also states that tiles dried by microwaves are on the average 25% stronger than those dried by traditional methods. He states that the major disadvantage of the microwave method is that of the cost of the magnetrons and the running costs. The cost and regular relacement of the magnetrons is prohibitive but it is suggested that it is the kVa requirement which is another prohibitive factor. It is disputed that the power cost is a negative factor. To reduce the power which would have to be provided Mori proposes a mixture of infrared/microwaves to optimise costs. He also maintains that dryers would have to be custom built to suit different absorption factors for different materials.

Bucker and Stahl[42] in 1981 considered hot steam drying, infra-red and high-frequency drying, contact drying and other drying processes as uneconomical.

Hamlyn[43] claims that work on microwave drying has lead to a commercially available process for drying ceramics and reports on the the joint project between Midlands Electricty and Staffordshire Polytechic to fire earthenware.

The success of the tests confirmed, not only the feasibilty of firing earthenware with microwaves, but also that reduced firing times and energy usage could be expected. In a private communication, Professors Besserling and Case calculated the initial cost and the cost of the biannual replacement of magnetrons for drying bricks to be prohibitive.

Markert and Diedel[44] used a commmercially available chamber dryer to test dry clay roofing tiles. Their paper suggests the use of microwaves to heat the product initially up to 70°C. This was achieved in 1 minute 10 seconds, another case is quoted of 50°C in 30 seconds and it is suggested that magnetrons be set in a tunnel so as to heat the ware to the required starting temperature and then to dry them in a conventional dryer. This is an aspect that must be tested with bricks and evaluated against steam and hot water heating. The initial reaction is against the perceived industrial health hazard of microwaves and the fact that the steam/hot water option has the advantage of reducing the volume of water added.

- Vacuum drying.

Art Ceramiche SRL(Italy) provide technical specifications for their rapid dryers. The "AFT" Series has been designed to work under vacuum for drying sanitaryware, tableware and tiles. Vacuum drying has not found application in the brick and hollow block section of the heavy clay industry.

2.5 THE HEAT PUMP AND DEHUMIDIFICATION SYSTEMS.

Howden Aircontrol (U.K.) claim, in a sales brochure, that there is no limit to the size and layout of the Howden Chamber for drying ceramics. The brochure explains the heat pump principle and quotes air velocities in the chamber as well as the option of additional auxiliary heater banks in front of the recirculation fans, but gives no indication of relative capital costs. The figures given for "illustrative purposes" as 45°C and 70% RH at the inlet to the dehumidifier and 49°C and 52% RH at the outlet, provide an indication of expected drying rates and water removal. Enquiries of local suppliers have indicated that the capital cost, in the light of the volumes of water to be extracted, preclude this as a reasonable method of drying large volumes of bricks and blocks. Heat pumps are discussed further in this literature survey.

Riedel(45) says that this method of drying has not found application in the Heavy Clay Industry.

2.6 HEAT SOURCES AND AIR MOVEMENT IN THE DRYER

Air is the convection medium and it also removes the water vapour. As stated above, advantage is taken in Europe of internal heating, in the dryer. As gas is the main fuel used, combustion can be good, resulting in smoke free dryers. In South Africa, because coal and heavy fuel oil are the main fuels used, heat exchangers have to be used to achieve smoke and SO_2 free drying. This precaution is usually ignored to the detriment of worker's health and product quality.

In the past dryers were sometimes heated by gilled steam pipes or exhaust steam under the floors. In both chamber and tunnel dryers there have been a number of geometric variations on the positioning of fans and ducting to achieve more even air and heat distribution. This was done to attain uniformity of drying with better heat transfer and greater energy efficiency. Some designs have used either internal or external heating with or without recirculation, sometimes taking advantage of the enthalpy in the wet air by reheating it before recycling it.

2.6.1 Impulse or intermittent drying

After 1960 the idea of impulse drying found favour with dryer designers. In 1976 Liesenberg(46) pointed out that for the decade prior to his lecture, various drying methods had been developed on the "rhythmic drying principle", although it was a principle which he had encountered 40 years previously. Benev(47) concludes from his experiments on the correlation between dry bending strength and moisture content that impulse drying was superior to continuous drying. His impulse times ranged from 1:10 to 1:40 being the ratio of blowing time to the calm phase time. Ford(48) describes two patented mechanisms for focusing a jet of relatively high velocity air intermittently, on the ware. They were patented under the names of "Rotomixair" (Novokeram Max Wagner Gmbh.) **[FIGURE 2(a) & (b)]** and "Reciprojet" (Fan Systems Ltd). Travelling fans, which pass up and down a dryer, provide a variation of the impulse air principle.

Thater(49) lists the advantages of intermittent feed as opposed to a simple continuous air flow:

- Long paths for the air feed are split up.
- Leeward sides are largely avoided.

These first two points are a result of the fact that fans are either moving or rotating.

- A pause and recovery time is introduced - reducing the differential between the first and last brick to dry.
- Faster drying with lower stresses is achieved.

- It permits more rapid heating of the charge - which implies an energy saving.
- The dryer capacity is enlarged by 2 - 2,5 times.
- This method is advantageous for perforated products.

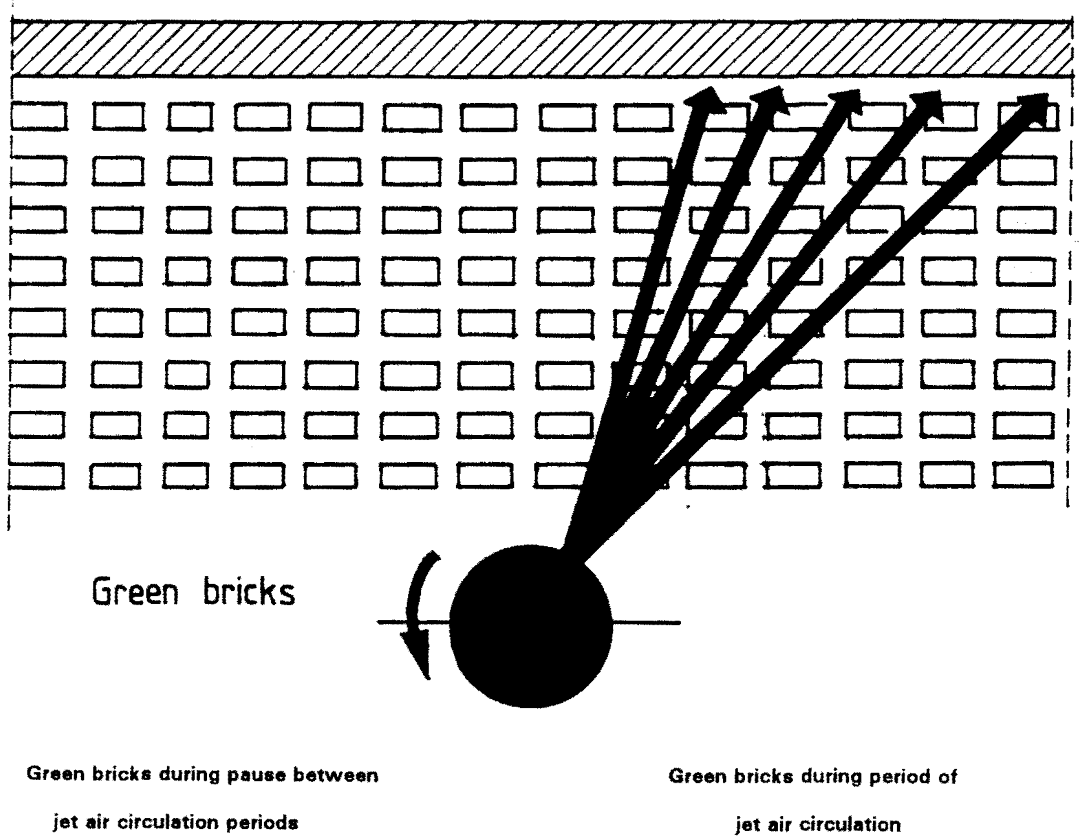
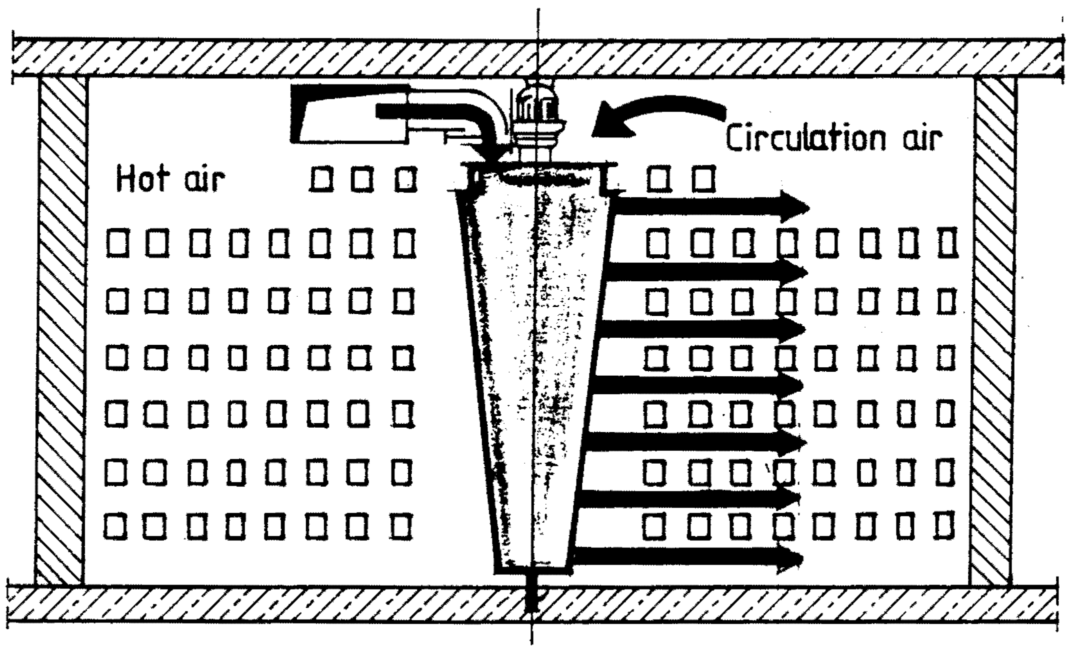


FIGURE 2(a)

The advantages of intermittent air flow having been established, considerable debate took place on the methods of achieving an optimum solution. One of the protagonists for large fans was Lingl and against were Wagner and Thoma of Novokeram with support from Thater[50] who is an independent consultant.

Liversidge[51], whose company installs the rotating cone type similar to Novokeram, recommends the travelling fan cluster,or fan column, claiming that the rotating cone, in spite of it's greater power consumption, has inadequate penetration. This is refuted by Wagner and Thoma[52]. Their paper explains their product well and explains the mechanical and maintenance advantages clearly.



Rotomixair

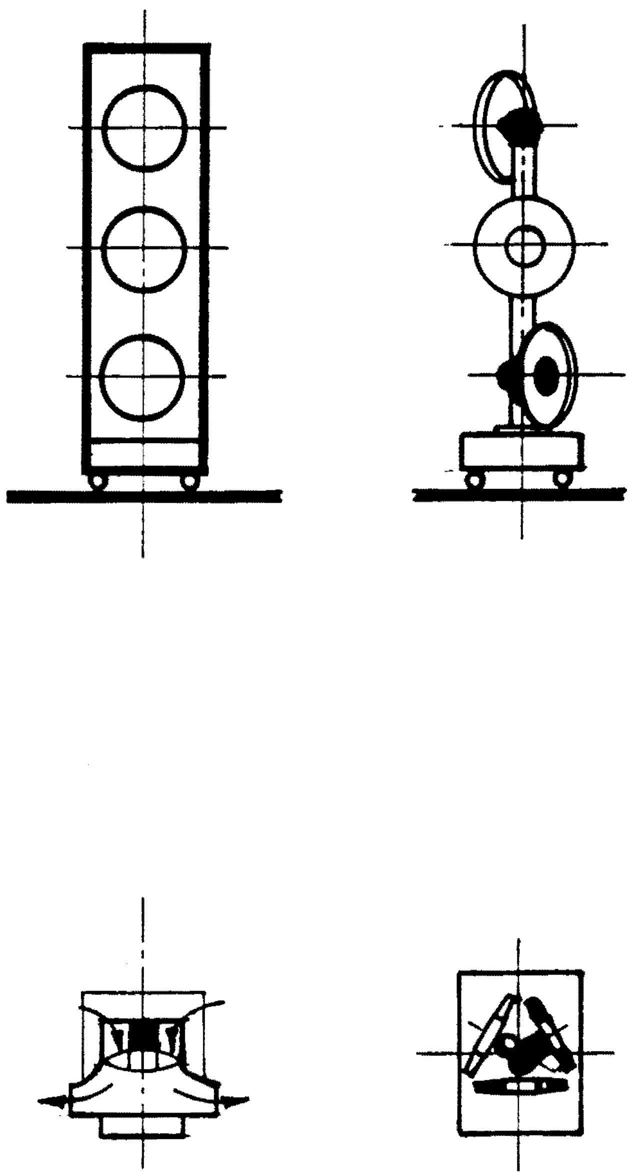
FIGURE 2(b)

Incidently the fan cluster, which is a set of three fans set one above the other, was offered by Keller in a quotation dated September 1990. **[FIGURE 3(a)]**

Further references to the debate are Thoma(53) and particularly two papers by Thoma(54)(55)in 1992.

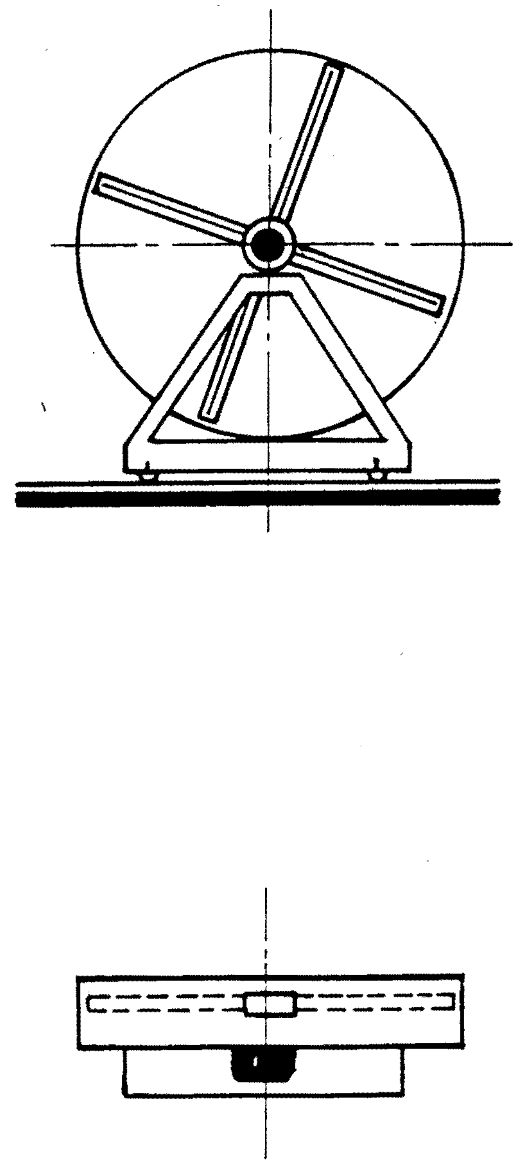
In the first of what was promised to be a series of three papers, Thoma and Wagner(54), compare and comment on opinions and prognoses published in the past and indicate to what extent practical developments have deviated from earlier theories. Thoma and Wagner who are respectively, Manager of Research and Development and Managing Director of Novoceram Max Wagner GmbH, also enumerate the fan systems which have been marketed commercially.

They attack Lingl[56] who states, in a paper still reproduced by Hans Lingl GmbH.,and also Lingl[57] that large area fans **[FIGURE 3(b)]** hold a significant advantage with regard to circulating capacity and power consumption over the so-called rotating fans. They prove their contention as to the superiority of the rotating fans and consider the power argument of Lingl to be based on false premises.



Fan columns

FIGURE 3(a)



Large area fans

FIGURE 3(b)

Lingl[58][59] concedes that in recent years they have been using large area fans combined with vertical jet units for standard dryers. It should be noted that the two subsequent papers will not be published due to a compromise between the companies concerned.

Another area of dispute between Thoma and Wagner[54] and Lingl[58] is the decision whether to synchronise the rotating fans or not, and further when the rotation should be speeded up and when it should be slowed down. Thoma offers more convincing reasoning in favour of random rotation and provides figures to prove his point. Lingl has a good argument in his technique of rotating the fan through 180^{o} and then reversing it. In 1991 Lingl[60] continued to press his points.

The concept of "Humidity drying" was first employed in Germany in chamber dryers. In this process virtually no moisture was removed from the ware in the initial stage of drying. Hot saturated air was circulated in the dryer in an attempt to raise the temperature of the clay body uniformly. Once the temperature of the wet body had been raised the ware was then subjected to a flow of hot dry air until it had been dried.

Stahl[24] describes the "Climatic Dryer" where heat is supplied to the dryer quite independently of the air intake by heating the recirculated drying air either directly with a burner or by heat exchanger. He states " This is the only method by which it is possible to control the climate (i.e. both the temperature and moisture of the drying air simultaneously), throughout the entire drying period in a manner best adapted to the properties of the ware."

2.6.2 Solar Drying

Plastic Tunnels have been used at Cullinan Brick, in the Transvaal, with air movement induced by fans. Wagner[61] expessed his opinions on his expectations of solar energy drying, as a possible method of drying bricks, in a general discussion paper.

Abdelrahman[62] reports that his experiment, not only improved the quality of the bricks dried with a fan and a solar air-heating panel but that these bricks had less shrinkage and dried in 40% less time than the 25 days required in the open air. No explanation is offered as to why the shrinkage should be less. Normally the improved quality can be ascribed to more even and more complete drying. In any case the first phase of drying usually determines shrinkage. Wagner[61] gives energy figures per square metre, which puts the possibility of using solar drying in industrial applications in perspective. While rejecting solar brick drying as an alternative at present it must be noted that Kauder[63] has built a prototype brick kiln,(at the University of Dortmund) which fires at 1000°C.

2.7 INDUCED AIR-FLOW.

Convection drying implies movement of air and this section deals with papers published after 1960 which, according to Thoma and Wagner[54] marked a period of fundamental changes in dryer construction.

2.7.1 Through-flow as a solution to uneven drying in large perforated blocks.

The adjustment of air-flow conditions to suit the optimum drying curve, for a particular product, is not only necessary to achieve the fastest, safe drying rate and maximum econonmy but is often the criterion as to whether a product can be produced or not. This is a problem experienced particularly with the drying of large-size vertically perforated clay blocks.

Schockert[64] reports on a study by the IZF (The Brick and Tile Research Institute of Essen.) which sought to solve the problem, after reports from industry indicated that internal cracking cannot be prevented even by prolonging the drying time.

The research was concerned with studying the effect of the drying rate, as well as the part played by the variation ofthe setting and of the velocity of the drying medium on the incidence of cracking in these large blocks. He claims that qualitative investigations made it possible to determine the exact extent of the influence of these parameters. These results provided an indication of what success could be expected by introducing measures to minimise or eliminate the internal cracking and the effect that these measures would have on the dryer's performance. The results of these tests and those of passing a continuous air flow through the perforations of the large-size blocks are reported by Prof. Pels Leusden in Ziegeleitechishes Jarbuch 1981. Schockert states that one important fact emerges from this report, namely, that the causes of cracking fall into two categories.

- Cracking caused by an excessively high drying rate.
- Cracks which arise because of local differences in drying rates.

The paper is concerned with the latter problem and particularly the air passing through the perforations in the large blocks and its effect on the surfaces of the perforations. He lists three problem areas:

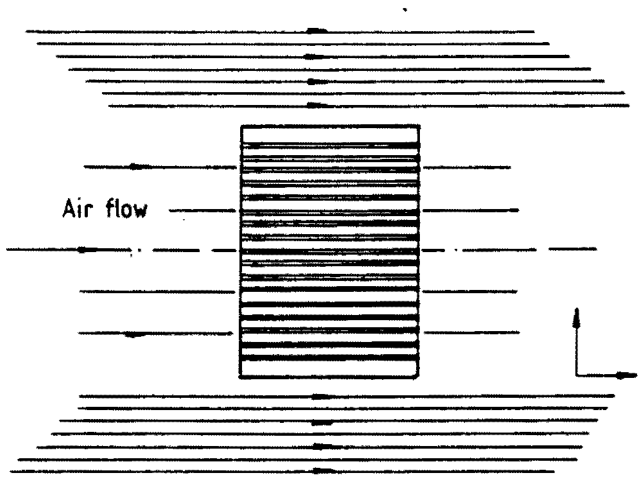
- The size difference between the internal surface areas and the external surface of the block.
- The differential flow rates inside and outside the block.
- That, because there is a larger surface area within the perforations of the block, this air will be more rapidly satuarated than the air flowing on the outside of the block - this will create a drying differential.

		VARIATION		
		MIN	MAX	DIM.
$X_{0.05}$	Drying rate	0.3	3.2	$\%h^{-1}$
w	Air flow rate	0.6	3.0	ms^{-1}
A_{qe}	Air recirculation Xn	474	1580	cm^2
l_x	Dist.between the green bricks in direction of flow	3	26	cm
Rb	Crack width	-	-	mm
n_x	Green brick position in dir^n of flow	0.5	4.5	-

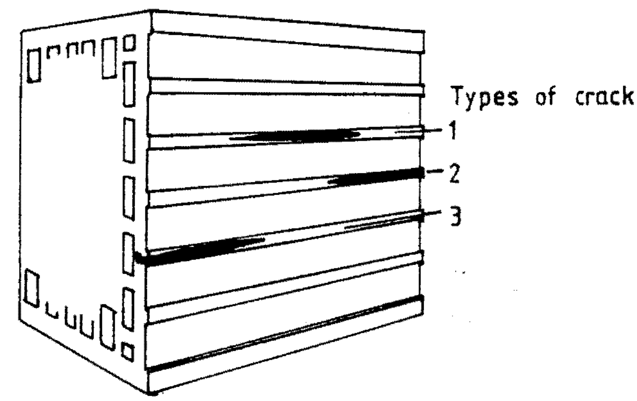
A variation of parameters (Schockert[64])

TABLE 1.

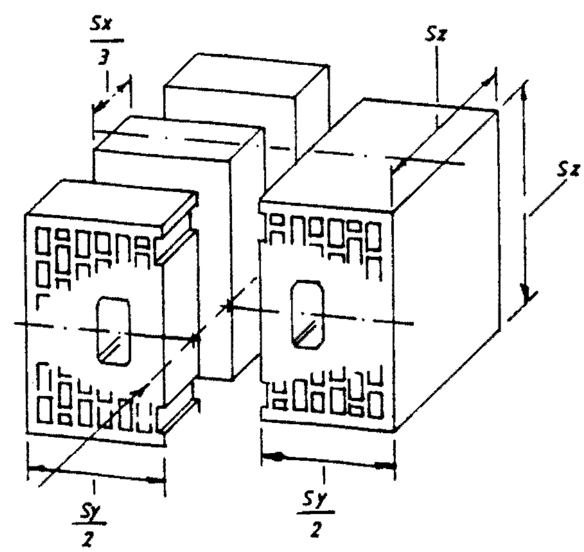
The parameters investigated were **X** the rate of drying, **w** the flow rate and l_x , l_y, l_z, which are the spaces between the green product and its neighbours on three sides. I_y and I_z were combined for a cross-section A_{qe}. The limits selected are those quoted in **Table 1**.



4(a)Air flow w.r.t.the holes in the block



4(b) The types of cracks in the block



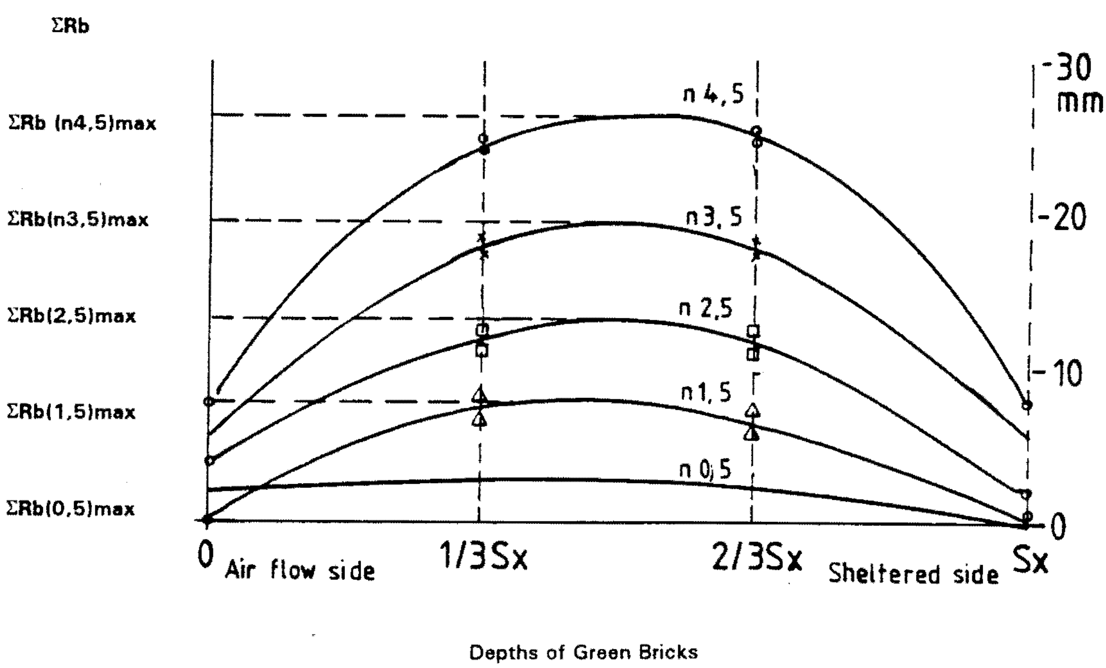
4(c) The method of evaluating the cracks. Schockert (64)

FIGURE 4

The cracks are described as "usually lens shaped". This is interesting, as often when cracks develop through differential drying, as happens with the edge of tiles, the crack is wedge shaped initially say 3 mm at the widest and can close up to a hair line crack when the body is completely dry. Possibly Schockert did his measurements when the blocks were not completely dry to get more measureable cracks. This would be good practice for a qualitative analysis, but caution would have to be exercised if quantitative conclusions were drawn. Half blocks were cut in three at right angles to the direction of the flow of the air.

[Figure 4] indicates in (a) the direction of air flow with respect to the direction of the holes in the block, in (b) the types of cracks and (c) the method of crack evaluation.

The sum of the maximum crack widths was measured, with a gauge, on each cut surface and on both the leeward and windward sides of the block, the crack widths for each surface were added together and plotted against the depth of the green block.**[FIGURE 5]**.



The crack widths plotted against the depth of the product Schockert [64]

FIGURE 5.

The sum of the maximum crack widths for each block was selected as a measure of damage. It was assumed that the variables tested had effects of varying magnitude on the blocks, each dependent on its position in the row, parallel to the direction of air flow, so therefore each row of blocks was evaluated separately using the following mathematical formula.

$$\text{constant} \cdot X^{\chi} \cdot A^{\alpha}_{qe} \cdot w^{\psi} \cdot l^{\lambda}_{x} = \Sigma Rb(n_x)_{max}$$

where χ, α, ψ and λ are indices.

Nomenclature	
X	Drying rate
A_{qe}	Area cross-section (using variables l_y and l_z)
w	Flow rate
l_x, l_y, l_z	Space between green brick and it's neighbour.
Rb	Crack width
n_x	Position of green brick in direction of flow.

Table 2. is a tabulation using the formula and results of the separate evaluation for each row of green products. (Schockert[64]).

	$n_{0.5}$	$n_{1.5}$	$n_{2.5}$	$n_{3.5}$	$n_{4.5}$
const	1.749	0.060	0.012	0.006	9.360
χ	0.61	0.84	1.12	1.12	0.54
α	0.17	0.70	0.99	1.19	0.17
ψ	-0.68	-0.62	-0.90	-0.82	-0.68
λ	-0.01	-0.16	-0.28	-0.36	-0.39

An evaluation with each row of blocks using the set formula.Schokert[64]

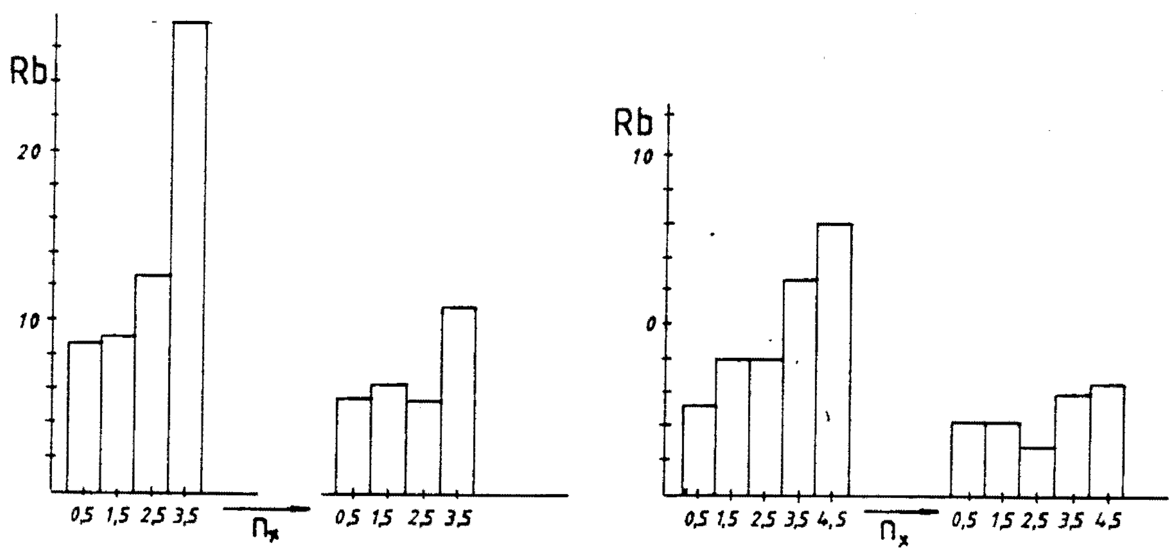
TABLE 2.

The exponents associated with the variables, if positive, are disadvantageous to drying and should be kept low while those which are negative should be larger to diminish cracking. Schockert's first conclusion is that "the increasing indices of the flow rate therefore provide evidence of the through flow problem." In **Table 2.** the indices of **w** do not in fact increase from blocks n_1 - n_5 (even if he excludes block n_5, which he says has a special(last) position.) and in any case, as he comments, there is a direct correlation between the rate of drying **X** and air flow rate, **w**. These two parameters have diametrically opposing effects on the cracking phenomenon, which opinion is borne out in **Table 2.** The reason for this is that the flow rate is important as a means of overcoming resistance in this system while in this case it is disadvantageous because a faster flow rate implies better material transfer and therefore a faster drying rate. He confirms this when he argues that an increase flow rate must be accompanied by a reduction in psychometric difference so as to maintain the same drying rate. His second conclusion is that the cross-section area can be reduced to match the area of the perforations and we would have,in effect, one large block - a conclusion which hardly required a mathematical formula or even a simple experiment. His comment on the significance of $\mathbf{l_x}$ is that, because of the greater surface area within the perforations, as compared to the outside surface, there is differential saturation of the drying medium and that sufficient distance must be allowed between each "batch" (l_x refers to blocks) for thorough mixing. Considering that a large block will be of the same magnitude as his largest value of $\mathbf{l_x}$ (26 cm) mixing is very unlikely. On the other hand if he slows the drying rate by raising the humidity of the drying medium then the differential humidity referred to above will possibly be irrelevant.

In conclusion Schockert submits two sets of test results to show the relationships found between rate of drying, flow velocity and setting pattern **[FIGURE 6]**.

Conclusion:

Schockert's paper does not inspire confidence in the thoroughness of the investigation. A basic premise is that there is a differential in drying within and without the block which is caused by a different flow rate of the drying medium, within and around the block, which causes cracking. The paper claims to provide mathematical justification for adjusting the setting, which is surely a matter of simple geometry. It is strange that temperature as a vital parameter is ignored as a variable, as this is an inherent criterion in determining the drying rate. The graphs in **FIGURE 5**, clearly show that cracks increase in magnitude from position 1 to 5 and that there are larger cracks in the middle than on the outside of the block, the position of the block in the row is the aggravating element. Intermittent air flow as a possible solution, or factor, seems not to have been considered. An immediate reaction is that the cracking problems could perhaps be eliminated by drying "one high" using high velocity intermittent airflow.



$X_{0,05}$ = 0,81	3,23 $\%h^{-1}$	$X_{0,05}$ = 0,75	0.73 $\%h^{-1}$
w = 0,6	3,0 ms^{-1}	w = 3	3 ms^{-1}
A_{qe} = 1580	798 cm^2	A_{qe} = 1580	1266 cm^2
l_x = 4	26 cm	l_x = 4	20 cm

6(a) Test results Schockert(64) 6(b)

FIGURE 6

2.7.2 Wind tunnel tests on air-flow, in the dryer, settings.

Reinders, Pels Leusden and Webber[65] simulated operational conditions as closely as possible in a wind tunnel in the laboratory and determined the maximum possible average drying rate, for the bricks which were being tested. A crucial aspect of this statement is the fact that a compromise from the maximum drying rate is made for an achievable average due to limitations dependent on the setting. This paper stresses that the permissible drying rate is not related purely to the material but proves that the flow rate, the setting and their interrelationships are significant factors. The incidence of cracking was regarded as the limiting factor for an acceptable drying rate. In the paper they examine the effect of changing the brick settings by varying the number of bricks per set of laths, the blade widths and the rack intervals - they experimented with five different air low rates. Of particular interest is the reference to a mass transfer coefficient β in drying, which is completely analogous to the heat transfer coefficient β "In combination with a water vapour pressure gradient from the specimen surface to the ambient air, this coefficient gives the volume of water expelled per unit of time." Prof. R.K.Dutkiewicz, in a private communication, indicates that the vapour pressure gradient within the brick must be considered. This suggests that there is a covariance between the material characteristics of the clay and the temperature gradient which is directly responsible for the vapour pressure gradient and this latter variable will effect the mass transfer coefficient. The higher the mass transfer coefficient the higher the drying rate in constant temperature and humidity conditions. Using the method of Kruckels and Kottke they determined the "local mass transfer" by wrapping the bricks, to be tested, in indicator paper saturated with a solution of $MnCl_2$. Ammonia was added to the air flow, which reacted with the $MnCl_2$, to give a brown colouration. The intensity of colour was quantitatively determined using a photometer.

The paper quotes a formula obtained by Stuppperich which establishes a relationship between the mean drying rate and the airflow conditions.

The mean mass transfer and therefore the mean drying load is as follows:

$$\beta = 0.14 \;.D/1 \;.Re^{0.68}$$

The formula is claimed to be valid for all setting patterns with uniform through air circulation and all flow rates. In the formula β indicates the mean mass transfer for the total green bricks, **D** the diffusion constant and the value **l** is the length of the brick in the direction of flow. The numerical value of l is also used in the Reynolds Number **Re**:

$$\mathbf{Re} = \mathbf{W} \cdot l/\upsilon$$

W, the flow rate, is at the narrowest part of the setting, the cross-section where one can see through the setting. This formula indicates that to double the flow rate would result in a mean mass transfer increase of 60% while doubling the length of the brick reduces the mean transfer by 25%.

The number of bricks on the laths and the number of layers of laths for the chamber dimensions are important as is the flow rate at the narrowest cross-section. This relationship takes no account of drying defects. Another aspect not accounted for in the relationship is the distance between the blades of bricks. Although the mean mass transfer is not altered by the distance between blades, if the distance is too small, there will be a lack of uniformity of drying in the brick which will cause differential shrinkage and drying defects.

The effect, of the distance between blades, on the uniformity of drying and therefore drying defects is thoroughly explored by Reinders et al. using $MnCl_2$ indicator paper and ammonia. An example is the comparison of two blades set 20mm and 320mm apart respectively, with air velocity in the order of $2{,}5ms^{-1}$. In the case of the first the differential mass transfer between the windward minimum and the edge maximum is a factor of 8-10. In the second case, which is the open setting, the difference between maximum and minimum mass transfer is a factor less than 2. It was found that increasing the air flow increased both the valleys and the peaks proportionally. The practical application of this information is that minimising the differential will allow an increase in the mean permissable drying load and speed up drying. The conclusion reached from the wind screening observations was that differences on the windward, relative to the leeward side, could only be significantly minimised when the distance between the blades or bricks was more than half the width of the bricks. With a separating distance somewhat greater than half the width of the brick a phenomenon termed a "separation current" further assists in evening the drying load on the edge zone. The significant conclusion derived is that with a distance between the bricks of twice the critical distance, in the direction of air flow, the brick can be regarded as "a free-standing individual body subject to direct air circulation."

2.7.3 The effect of reversing the air-flow in a batch dryer.

Pels Leusden(66) examines the effect of reversing the airflow at regular intervals, through 180^o, in a batch dryer. He says that in most cases the efficiency of the dryer is improved by 2,5 times that of the same unidirectional dryer. In another part of the paper he clarifies the claim in that with sufficiently frequent reversals, of air-flow, the throughput is increased by a factor of 2,5. These dryers recirculate the air continuously, bleeding in fresh hot air at between 170^{o}C and 200^{o}C in the ratio of fresh air to recirculated air of anywhere from 1:4 to 1:20. [While his paper is confined to batch dryers, he points out that the principles established can also be applied to tunnel dryers.]. Unidirectional, constant air flow, batch dryers have the distinct disadvantage of drying the bricks progressively in the direction of the air flow, necessitating prolonged drying times after the first rows have dried.

His treatment of the results by plotting relative drying times against relative drying loads, as well as using the concept of "transfer units" allows direct application to batch dryers of any size. A typical example quoted is that of the first row reaching the end of the critical shrinkage range after 12 hours while the last row reached the same condition after 46 hours with unidirectional air-flow.

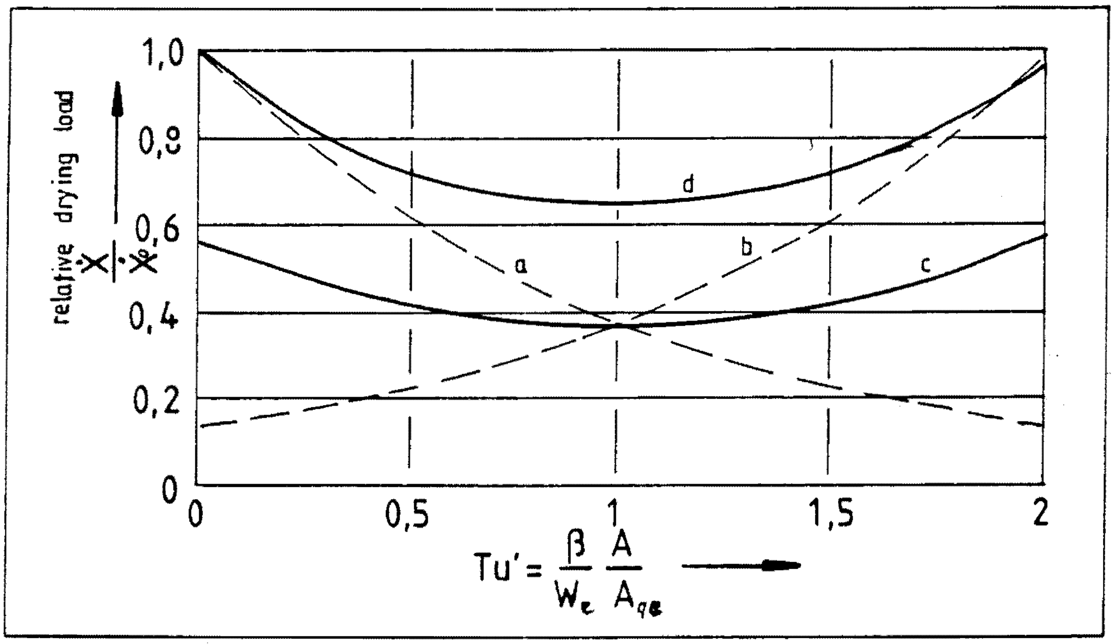
Pels Leusden maintains that the intention of the inventor of the first "reverse flow" batch dryer was to achieve "Rythmic drying". This method applied an intensive drying load to the bricks for a short time and then allowed a pause which enabled the water to migrate from the interior to the surface.

He says that the success of the reverse flow system was in fact due to the evening out of the drying by the reversal of the air. He quotes the tests and calculations of Prof. Stupperich (IZF. Essen.) which establish the most favourable conditions for operating a reversal flow batch dryer.

The results of the argument are adequately summarised in **FIGURE 7**. which is concerned with Phase 1 of the drying curve.

The explanation of the example is as follows:
Line **a** is a plot of the change in the relative drying load along the line of air flow. When the air flow is reversed through 180^{o} the counter-curve "**b**" is produced. If the flow reversals are infrequent the two ends are subjected to loads up to the permissable limits and the drying time for the last bricks to dry is reduced. Line "**c**" is the plot of a frequently reversed flow and gives a mean load of 55% of the maximum load of a non-reversing dryer and quarters the differential of the load difference in this example. This allowed an advantage as shown in **d** where it was possible to increase the temperature differential between the air and the bricks by 78% which resulted in the last bricks drying at 66% of the maximum. He also deduces from Stupperich that increasing the air reversal frequency permits an increase in velocity of the air and/or the temperature for safe drying. This argument is contrary to the frequently quoted statement about "Rythmic Drying" which claims that a pause allows water to migrate to the surface, immediately after the surface moisture has been scrubbed away. Stupperich therefore corroborates the opinion of Prof. R.K. Dutkiewicz quoted above.

The above discussion applies to drying Phase 1, but after shrinkage has taken place, and Phase 2 starts, the rate of drying decreases and the next brick in the line of the air flow now increases in drying rate so that, while the differences are greatest in the drying load between the first brick, and the bricks in the middle of the dryer, at the beginning of the cycle, once the shrinkage phase has been passed the differences become progressively less. The example quoted indicates that approximately half of the mixing water is removed in the shrinkage period and the remainder in the second phase takes almost four times as long to be removed.



The drying load of green bricks in the initial drying phase as a function of the position of the bricks in the dryer in the direction of the air flow.

a) during air flow from left to right

b) during air flow from right to left

c) mean load on bricks from loads a and b

d) mean load on bricks, with operation as at c), but with the temperature difference between the fresh air and the bricks to such a degree that the mean load on the bricks for Tu' = 0 and Tu' = 2 is as high as for a) and b).

KEY TO SYMBOLS IN FIGURE 7

X = drying rate

X_o = max. drying rate

w_e = air velocity

Tu' = transfer units

β = mass transfer coefficient

A = drying surface area of setting

A_{qe} = X^n of drying air circl^n between bricks (initial)

FIGURE 7.

2.7.4 The effect of a jet stream on large-size vertically perforated clay blocks

In an attempt to reduce drying times, a continuous tunnel dryer was planned with blocks passing through rows of slot-type jets, on alternate sides, with thorough air circulation.

Kother(67) set up test equipment to test the effect of a jet stream on individual webs of a vertically perforated clay block. The purpose of the research was to achieve uniform drying in the block, particularly on the internal and external web surfaces.

The mass transfer was determined by the Manganese chloride indicator paper strip method of Kruckels and Kottke referred to above. More satisfactory results were achieved with a 20mm wide slot as against a 10mm slot, the conclusion being that the jet slot width should be greater than the perforation width but less than the sum of the perforation width plus the web width. The distance between the jet and the block should be as short as possible and an air velocity of 30m/sec is found to give better results than velocities of 10 or 20m/s. Reversible air flow was found to be indispensible. This latter observation should be tested because if there is only one block being subjected to the air flow it would be reasonable to have the "bounce back effect" experienced by Novokeram and their intermittent fan system. In this case it is found that the tenth tile, which is the furthest from the air source, dries faster than the seventh tile, supposedly because of this effect, (Thoma and Wagner(52)).

In 1991 Hencke and Hein(68) wrote a paper on the drying of tiles and they conclude in favour of rotary fan units as against jets. They suggest that the rotary units are less expensive and are more versatile than a jet system.

It is surely an engineering problem, to establish logically the most suitable method of arranging for air to pass as evenly as possible through and around the green product using the minimum possible electrical energy.

Lingl[69] makes a strange statement on page 28 of his paper, "In the last third (of a tunnel dryer), high velocity hot air is blown down from the ceiling towards the floor, between the dryer cars, without need of artificial circulation, since only temperature, not a particular set of airflow characteristics, is of importance for last stage of drying". Surely at this stage better heat transfer would be achieved with turbulence in the pack.

2.8 ENERGY RECOVERY AND EFFICIENCY.

Handle[70], in considering the brick industry in the year A.D.2000, predicts the possibility of a 50% reduction in fuel saving which includes a reduction in specific electrical needs of 25%. It is not surprising, considering the cost of energy and the environmental concerns, that a large number of papers are written suggesting methods of reducing energy consumption.

2.8.1 Stiff extrusion.

Steele [32] refers to the reduction of between 10 to 18% of the water which has to be removed in drying due to stiff extrusion and claims that it is doubtful whether the total kW requirement, from raw clay to green brick, is any greater for stiff than for soft extrusion, even though the actual extrusion requirement is greater. This statement is acceptable due to the lower clay preparation costs.

2.8.2 The "Gasegeno-process"

Gatzke [71] proposes the use of ash-rich coal, which is typical of South African coals, in a Gasogen Reactor to produce a uniform combustion product for the dryer and a fine-pored ash and light-firing bituminous coke which is added to the clay for extrusion. The reactor for the Gasogen Process can run parallel with the plant and be stopped and started at night. Environmentally it means that the problem of low-temperature carbonization gases which pollute and cause a loss of 25% of the energy when the coal is added directly to the clay, is eliminated because the gas is now efficiently burnt in a combustion chamber in the dryer. **{APPENDIX 2.1}**

2.8.3 Direct air heating.

De Leeuw [36] records a saving of 420kJ/kg water evaporated on a dryer in the Netherlands which was converted from hot-water air heaters to gas burners.

2.8.4 The rationalisation of energy usage.

Hohr [72] raises interesting alternatives to electrical energy and rationalization of energy consumption in a brickworks. He suggests suitable heat exchangers and possible solutions to problems which might arise in their application.

2.8.5 Heat pumps.

The article[73] on the Howden Dehumidification system for the ceramic industry referred to earlier, claims that " the ....system is completely flexible with a range of units to suit any size and layout of drying chamber." Although the heat pump principle is proven, local supplier opinion is that the volumes of water to be removed make this method of drying unsuitable at present.

Bellaiche[74] describes the drying of sanitary ware in Karachi, Pakistan, where climatic conditions are severe. Ceric of France have installed a heat pump system where the ware is dried in the casting hall in 24 hours using heat pumps, removing 7000kg of water per day. He claims that in Europe the amortization of a similar plant would be achieved in 8 months.

Riedel[75] argues that 79% of the heat feed to a dryer is dissipated, unused, in the waste air. He discusses the disadvantages of waste heat recovery, from moist air at 50°C, by heat exchangers, particularly if air is coming from the kiln at temperatures above 50°C, or if internal heating is used. He calculates that using a heat exchanger, raising air at 8°C and 100% RH to 40°C which then contains 31,8kJ, will only provide 16% of the heat required to heat the usually very small amount of air used for this partial air flow and if the partial air flow is one third of the total drying air volume then there is only a 5,3% saving. He explains the heat pump principle and argues that heat pumps have not found application in brick factories because of the low temperature level of normal heat pumps. He claims that heat pumps generate air at 58 - 64^{o}C. He calculates that to exhaust at 50^{o}C and 80% RH which is regarded as standard good practice, a hot air temperature of 200^{o}C is required. A lower temperature implies higher air volumes and greater exhaust losses. To be able to achieve this temperature in a heat pump a different refrigerant would be required from that in commercial use. The boiling point and condensation point of the refrigerant would have to be adapted to the temperatures in the evaporator and the condenser respectively. It would also be necessary to increase compression for the higher temperature which would increase power costs. With the present heat pumps Riedel claims that as against a heat exchanger saving of 5,3% the heat pump would offer 8,6% saving plus a 3% running cost which implies merely higher capital cost with no benefits.

Riedel then offers a compromise, he suggests that the heat pump can be used to replace internal heating. The gas heaters or steam/hot water preheaters would be operated with the hot refrigerant medium of the heat pump. The condenser of the heat pump would be divided into several air preheaters installed in the drying chamber. He says that, using the correct refrigerant it would be possible to supply the air pre-heaters with temperatures of 80 - 100^{o}C. Futher he claims that there is quite a simple device for raising the temperature delivered to the heat pump by 18 - 20^{o}C. This arrangement would match steam heating and Riedel maintains that between 50 - 70% of the heat to the dryer would be supplied by kiln waste heat and the balance by the heat pump. The heat pump power costs would be less than the fuel costs for supplementary heating. Reidel is depending on so called "waste heat' from the kiln. This has been cleverly handled in his "Counter-travel Kiln", which he is now marketing and is referred to later. He now has enough air from his kiln at high temperature to satisfy the dryer needs and so makes this proposed use of heat pumps and secret "devices" unnecessary.

Meyer's [76] paper on heat pumps and alternative techniques suggests the use of independent electricity generators and the recovery of the exhaust heat as well as using gas or diesel engines to drive heat pumps to recover energy from waste air and waste heat within the factory. These suggestions have little application in South African conditions where factory heating is not a necessity and where electricty is cheap. His argument, to supply the dryer with air at 200°C, is to use gas waste heat from 3-phase rotary current plant units and use Wuakesha gas motors to drive the plant and generate cooling water with discharge temperatures of up to 125°C. With additional measurers, which he does not explain, he claims that water at 200°C can be produced.

Strohmenger, reported in Rieseler(77), also suggests the use of heat pumps on dryer exhaust for space and hot water heating.

2.8.6 Heat recovery from the dryer exhaust.

Although the dryer exhaust has a lower heat capacity than the kiln exhaust, Wagner(78) proves by examples, that if the appropriate heat recovery system is used, good recoveries are possible particularly if the dryer is operated independently of the kiln. He offers various alternatives for the use of heat exchangers and does his calculation on a medium sized dryer with 0,6 temperature effficiency for the heat exchanger. **{APPENDIX 2.2}**

Thater(79) records that the 40% heat loss through the dryer exhaust in most cases exceeds the kiln flue gas losses. He examines various techniques used in the past and proposes the patented "Thater-turbo" system(80). In this system exhaust air at 40% RH is passed over a heat exchanger surface and then heated by gas burners to give hot air with 10% RH. This is on the pressure side of the moist air fan and is indexed into the hot air duct. He claims that the volume of drying air is increased by up to 50% and therefore the pressure in the dryer is increased resulting in uniform air distribution, accelerated drying and a 15% heat consumption decrease. The increase in pressure is claimed to be the essential feature of the system. He completes his paper with examples of air at different temperatures and humidities being heated to different temperatures and indicates the heat engineering efficiencies. **{APPENDIX 2.3}**

Rimpel[81] reports on the results of the project "Waste heat utilization from dryers for the reduction of the energy required for the drying of heavy clayware" sponsored by the Study Group of Industrial Research Associations Regd. (AIF).

The basic false premise on which this whole report is based is the fact that one has to cope with waste heat from the kiln. On this assumption, which is valid for the majority of kilns, he then has to handle the problem of energy that is availble 24 hours per day and 7 days per week while the dryer load is unevenly spread as is indicated by Wagner[78] and Rimpel. The report has merit while waste heat is available from present day kilns (a German survey indicates that 80% of the heat for dryers comes from kilns).

Carey[82] quotes the Corobrik Driefontein tunnel kiln as exporting 38,8% of the net producer output to the dryer. For the purpose of this study the optimum situation is for the dryer to be self- sufficient in it's own heat source and then to quote Rimpel "the heat recovery process acquires special importance." He suggests a combination of a heat exchanger and a heat pump, in addition returning warm water to the mixer. He would want the whole dryer to operate in closed circuit.

A computer program was used for mathematical simulation of the drying process which enabled calculations of the energy processes in chamber and continuous dryers. Three graphs were plotted:

- the relationship between specific energy consumption and exhaust air moisture and ambient air temperature.
- the relationship between specific energy consumption and exhaust air moisture and feed air temperature.
- amount of exhaust air enthalpy which can be utilized by exhaust air recuperation as a function of the temperature of the feed air and of ambient air.

{APPENDIX 2.4}

From these graphs Rimpel is able, in the first case, to deduce the need to achieve maximum saturation and a high "raising of the ambient temperature". Secondly he deduces that ideally with low feed temperatures and a high moisture level in the exhaust, the specific energy consumption would be optimal, but in this case, it would mean slow drying and a low exhaust heat recovery. He also indicates the adverse effect that a high ambient temperature has on heat recovery and this has to be taken into consideration in South African conditions. In the third graph the exhaust air enthalpy latent in the exhaust of a "model dryer" is plotted as a function of the feed air temperature. This was the maximum energy available with utilization of condensation heat and ideal heat transfer. The values were calculated according to the inputs that the ware should be dried with the corresponding feed air temperature and that the exhaust saturation is 70% RH. His calculations, as stated above, are concerned with situations where, on average, 78% of the heat used for drying comes from the combined heat system and only 22% from the ambient air. Theoretically in a dryer with air feed at 150°C and 20°C ambient some 60% of the exhaust enthalpy can be recovered. This latter figure (12%) was confirmed by Rimpel on a chamber dryer with an exhaust recuperator.

2.8.7 Papers covering the wider spectrum of energy conservation in the dryer.

In 1985 Liesenberg(83) made the statement that heat recovery and optimisation of the dryer was pointless because the trend was that the supply of warm air from the kiln was being increased with faster production through the kiln. He believes nevertheless that there are possibilities for reducing heat releases from the kiln but warns that measures taken should deal with kiln and dryer together, guessing that savings of the order of 10 - 30% are attainable. This type of observation seems to indicate an obsession with what is operating at present and really only assists the plant in operation. Reidel's Counter-flow kiln, referred to above, appears to offer the ideal waste heat solution for drying. Kainer(84) has developed a good solution for high exhaust heat recovery.

Lingl(85) makes a plea for the heavy clay industry to break from it's dependence on oil and gas and to be prepared to use only coal. Against other opinions Lingl favours a compound heat system of kiln and dryer and claims this as necessary to achieve economic efficiency. He concedes that originally a 50% heat recovery from the kiln suited the situation when the dryers operated on a 7 day cycle but that now 30% is drawn from the kiln so as to accommodate the dryer's need over the week-end. This opinion, expressed by Lingl, is disputed in the work of Bucher and Stahl[44] quoted below.

He warns of the need to consider the power component for the air feed and circulation system and states that, while it is a relatively small proportion of the total energy usage in the dryer, this component has steadily increased over the past 20 years. (It should be noted that electrical power costs in the order of 3 - 5 times the coal equivalent.) The main criterion, for heat economy, is the temperature of the ware and air on entry and exit from the dryer and so he recommends a recirculation capacity five times that of the hot air capacity. This factor of five might well have to be increased if the dryer cross-section and the product size is relatively large. In this paper written in 1980, he argues for the use of large-surface low pressure fans, with diameters equal to the height of the drying chamber, for circulation, so as to reduce power consumption inspite of the larger volume of air which is moved. This particular subject, of large fans versus the higher pressure rotating fans used by Novokeram, was a source of debate over a number of years. It is difficult to understand why the issue was not immediately resolved by experimentation and calculation. Lingl have now conceded in favour of the ideas of Wagner at Novokeram and combine the use of large fans with high pressure, vertically installed, fans which give a better vertical air mix. It would seem that Lingl's solution is a compromise and that Wagner's high velocity intermittent fan offers a more elegant and efficient solution. Lingl claims that the power consumption of a chamber dryer exceeds that of the continuous dryer which is a unsubstantiated statement.

The rest of the paper is a repeat of drying truisms, recommending internal heating by gas, good insulation, which should be kept dry, low heat capacity stillages or drying supports. The dryer structure should have the minimum possible radiant heat loss and that the exit temperature of the ware should be as low as possible, constant exhaust and humidity temperatures are imperative and should be automatically controlled.

His suggestion for the use of regenerative heat exchangers with the kiln flue is interesting and should be considered, bearing in mind the damage that could be caused to the heat exchanger if the kiln exhaust temperature is allowed to drop too low before it's final emission through the stack. Bucker and Stahl(44) support this opinion and only recommend recovery from dry flue gases. (They refer to the economical use of heat exchanger systems with a liquid medium for heat recovery from dryer waste air.) Lingl further states that up to a third of the dryer heat requirement can be derived from heat exchange with kiln flues but makes an unsubstantiated claim that this improves the operation of the kiln.

Bucker and Stahl(44) state quite clearly that, with reference to the measurement of results and calculations carried out, that heat combinations of dryer and kiln are not advantageous from an energy point of view. The kiln should not be used to generate heat for the dryer. Again, here mention must be made of the need to test Riedel's Counter Travel Kiln and it's low volume high temperature exhaust, as an ecomomical solution to a dryer/kiln combination.

They list possible operating and process methods as energy saving measures:

- low initial water content and high residual moisture
- high operating temperature
- high saturation of waste air
- low final temperatures

They state that short drying times should be aimed at to reduce transmission losses but point out that saturation of the air requires time. The solution of this particular problem is a matter of mechanical engineering. They claim that the maximum permissible drying temperature for each clay must be determined in the laboratory.

They say that the only two factors which influence energy consumption are operating temperature and saturation. Ideally the highest possible temperature and the highest saturation of the air should be used. Reference is made to the increased energy efficiency and faster drying times achieved with internal heating. They deal briefly with the economic balance between the desireable increase in air velocity and the undesireable accompanying increase in electrical energy cost.

Of particular interest is a section on design possibilities dealing with short-circuiting of air and the costs of dryer leaks.

Rabuel(86)considers good energy housekeeping and mentions the savings achieved by replacing the central hot air supply and it's associated ducting and heat losses, with individual burners for each dryer chamber. This implies better recycling and easier control. He argues for automatic controls and a careful determination of what the residual moisture in the ware should be on leaving the dryer, as well as precautions to be taken to avoid reabsorbtion. In this paper (1983) he remarks that investment costs represent a brake on energy recovery from the dryer exhaust using a heat pump.

Thater(87) approaches energy conservation in this paper from the view point that improvemnts can be made to the typical plant without any structural changes. He offers the following practical suggestions:

- determine the Bigot curve for the clay,
- consider whether additives would improve the drying,
- monitor the condensation limits,
- establish the fastest heating rate and the maximum temperature load which the ware can stand,
- he suggests that the unit settings should be "open",
- he recommends an air circulation factor of 8-10 times the air input volume,

He refers to a tile plant which has a recirculation factor of 20 and he says this reduces condensation. He suggests settings that facilitate an air flow which penetrates the perforations, and draws attention to the need for adequate pressure ratings for fans to achieve penetration as well as air circulation.

He makes a point of restricting air feed in the final stage of drying and recommends 100mm thick glass wool as an insulator rather than mineral wools. He also records that 0,7-0,75 is the thermal efficiency of steam or water heaters and warns against their use.

Reiseler[77], referring to a paper presented by Pels Leusden summarises his suggestions for dryer energy conservation. He recommends a reduction of dryer leaks, internal gas heating and a hot air feed at 200°C.

Bellaiche[88] refers to research done by Ceric of France in the use of very precise electronic hygrometers and regulated air movement so that only the saturated air is extracted on a continuous basis.

2.8.8 The use of fans to reduce energy consumption in the dryer.

Stahl[89] describes the relationship between electrical energy costs and savings due particularly to the greater degree of saturation of the exhaust air achieved by increasing air velocity. He deals with "the basics of heat transfer in drying", "the influence of the condition of the air on heat consumption" and "the dependence of the heat transfer coefficient on the velocity of flow and the flow energy" **{APPENDIX 2.5}**

Junge[90][91] has produced two papers, on a test dryer which results are used to draw conclusions for industrial use. The first sets the basic principles for the research project establishing the relationships between fan properties, setting density, hot air feed volume, electrical capacity and energy data. He makes a comparative theoretical analysis of the physical processes occuring during the first phase of drying. The approximation to the drying process in a large-scale industrial plant and his mathematical model shows good correlation. The mathematical models used are the "agitator " and "piston-flow systems" developed at the Technical University of Clausthal.

He claims that in 1985 there was no adequate knowledge available of the precise effect of recirculating appliances on energy consumption. He makes a distinction between three shrinkage phases and three drying phases. His paper is concerned with the first drying phase which coincides with the **A & B** shrinkage phases.

He derives two simplified formula for the dimensionless waste air temperature Θ_2

- The agitator flow model

$$\Theta_2 = \frac{1}{1 + 1/St}$$

- The piston flow model

$$\Theta_2 = 1 - e^{-St}$$

Where St is the Stanton Number.

He states that these two formulae form a mathematical tool which can be used in the two models for the design of dryer systems.

The test dryer and test sequence:

- A disturbing factor is the fact that there is a "relatively small" flow through the perforations of the bricks, which according to previously quoted references, would imply a limiting factor to a more ideal system.
- It was found that the front row dried more quickly than rows further from the fans.
- The open setting gives a more even drying pattern within the chamber than the closer setting.
- The fan column promotes greater uniformity of drying than the individual radial fan.

These latter three observations hardly needed a mathematical model or a test dryer to prove them. What is of significance is the observation that in the test dryer "relatively high surface-specific electrical capacities produce approximately the same results with regard to the air feed enthalpy" but Junge later states " when it comes to transferring the "proportionality" found in the research project between the heat transfer coefficient and the surface-specific electrical capacity of the recirculating fans however, it is not possible to assume such direct conformity between the test results and values in industrial practice."

Concern is expressed about the conclusion that a specific electrical energy limit can be established from the experiment when the results are only related to the specific fan system used. This argument ignores the ineffectiveness of low pressure non-directed air streams and the use of high velocity intermittent air flow. This observation is borne out by Junge's statement that, from his experiment, the fan speed has virtually insignificant influence on the uniformity of drying. Further, "The assumption previously made that a change in the angular momentum due to the the blade setting, on the energy conditions and uniformity of drying was not confirmed in the tests".

2.9 THE ENGINEERING SYSTEMS.

- **Systems Engineering**

Schmidt(92)(93) has produced a two part paper on Systems Engineering which he describes as a modern or even **the** method of obtaining optimised solutions to problems. The method, although coming from the USA is claimed to have been perfected by the Systems Engineering Association at the Technical University of Zurich.

In the first paper he argues for the general application of Systems Engineering for the solution of problems. It offers a method from general conceptual, to the particular, and can find application at any level of planning.

In the second paper, Schmidt shows the special application of Systems Engineering to ceramics. Some four years before this Schmidt(94) wrote a paper on planning considerations prior to dryer construction according to systems engineering. This latter paper sets out the sequence and considerations for planning a dryer according to Systems Engineering and considers the influence on the environment of a closed system. While the method might appear to be cumbersome and time consuming it's thoroughness is attractive and because of the conceptual aspect seems to encourage lateral thought in problem solving. **{APPENDIX 2.6}** clearly illustrates the approach with reference to a dryer.

- **The Mechanical engineering system.**

In an editorial discusion paper featuring the opinions of Wagner[61] on drying, the requirements of a modern dryer are set out as follows:

- Flexibilty of performance.
- Flexibilty of products accepted.
- Minimal Heat consumption.
- Energy recovery and thermal insulation.
- Saving of space.
- Quality of drying.
- Simple and reliable programming

Of these points the engineering aspects are those of energy recovery, thermal insulation, space saving and simple programming. Wagner pleads also for continuous use of plant. He comes out strongly in favour of separating the kiln and dryer. What is most significant is his warning to countries using heavy fuel oil not to employ direct firing methods, but suggests that 98% efficiency can be expected from a steam or thermo-oil system. (It has already been noted that Thater claims 0,7-0,75 thermal efficiency for steam heaters.) At present South African brick plants use direct heating with both coal and H.F.O

- **Automation**

Rabuel[95] argues for the automation of setting, the conveying of ware and the charging of dryers. The paper is more than ten years old and so his suggestion that advantage be taken of electronic equipment as against electro- mechanical appliances is understandable. His argument for complex programmable systems, which he describes as disadvatageous even in Europe, would seem to be inappropriate in South Africa because of the training requirements and the meticulously exact analyses required to solve a problem. Advantage can be seen in the use of these programmable systems for the actual process control in the dryer. He quotes the drying programme in a specific chamber dryer where the hot air inlet is time and sequence controlled, temperature is controlled through gas burner modulation, static pressure of the hot air is controlled by changing the motor speed on the fan. Further a moisture probe first controls the air extraction and then the recycling according to set requirements. Although this method is initially more expensive to install it obviates the need to calculate damper openings and make laborious adjustments. Perhaps the most significant observation which he makes, relevant to this project, is the fact that because of the difficulty of staff controlling a complex and varying process, a cycle is implemented which includes enormous safety factors which are far from economic.

- **Climatic control**

Lindemann(96) sets out the need and means of facilitating the closest correlation between the "immediate climate" around the ware and the "dryer climate". This is a very practical paper setting out the criteria for ideal climatic conditions and control. It also offers setting criteria of the ware which has engineering implications.

- **Setting**

In 1962 a group of three major American brick manufacturers combined with three equipment suppliers to set up the "Rathole" research project. General Shale Products corporation was the first to carry through the total automation project. The British Clayworker(97) in January 1968 carries a report on the project and Jeffers(98) reports on this "one high" kiln in 1972 after 5 years of operation. The engineering aspects of interest are the fact that the bricks are set one-high "soldier". A slug of clay 28 bricks wide is cut and then pushed through a set of vertical wires. The bricks are split with slide plates and pneumatic fingers come between the bricks and after being inflated, rotate the row of 28 bricks through 90^{o} and place them soldier on the car.

The standard American brick is even longer than the imperial brick made in South Africa and in discussion with brick makers in America the stability of this setting was believed to be a major draw back and that the jarring of cars, during the push, caused a "domino effect". Another engineering consideration is the fact that Jeffers records that the kiln and therefore dryer cars are "standard heavy duty for long life" this is surely the reason for the relatively high energy consumption recorded.

2.10 THE USE OF THOMA'S h,x DIAGRAM.

Thoma[53] has revised the Mollier Diagram to cover the entire range of air conditions experienced in drying ceramic products.
Using the diagram he is able to determine:

- The dry air component β^* in kg/m^3 moist air.
- Water vapour content **x** in g/kg dry air of the moist air.
- Heat content or enthalpy **h** in kJ/kg dry air of the moist air.
- Theoretical heat required per kg of water expelled.
- The hot air temperature i.e. the hot air temperature required for the particular drying operation.

Other quatities are:

- **t** for temperature of moist air in ^{o}C
- φ for relative humidity in %
- $\Delta h/\Delta x$ for the heat consumption in kJ per kg water.

{APPENDIX 2.7}

He illustrates the application and significance of the diagram with reference to specific examples.

EXAMPLES OF CALCULATION WITH h,x - DIAGRAM

Section One

No	hot air	deg. C	Temperature of hot air	60	120	150	180	
1	t_1	^oC	Temperature of fresh air	20	20	20	20	
2	φ_1	%	rel. humidity of fresh air	70	70	70	70	
3	β_1	kg/m^3	Dry air component of fresh air	1,185	1,185	1,185	1.185	
4	X_1	g/kg*	Water vapour component of fresh air	10	10	10	10	
5	h_1	kJ/kg*	Enthalpy of fresh air	45	45	45	45	
6	β_2	kg/m^3	Dry air component of hot air	1,043	0,884	0,822	0,767	
7	h_2	kJ/kg*	Entalpy of hot air - enthalpy of waste air	86	148	178	209	
8	Δh	kJ/kg*	Heat expenditure h_2-h_1	41	103	133	164	
9	φ_2	%	rel. humidity of waste air	80	80	80	80	
10	t_2	^oC	Temperature of waste air	30	41,5	45,5	48,5	
11	X_2	g/kg*	Water vapour content of waste air	21,3	41,5	51,5	62	
12	ΔX	g/kg*	Water vapour absorption	11,5	31,5	41,5	52	
13	$\Delta h/\Delta X$	kJ/kg**	Heat consumption per kg H_2O	3565	3270	3200	3150	
14		%	Saving in heat consumption by drying with hot air at 180°C compared with hot air at 60°C.					11.7

* = DRY AIR ** = WATER

Section Two

No	hot air	deg C	Temperature of fresh air	60	120	150	180
15	M_{Tr}	kg	required dry air volume per kg water(= 1000/Δx)	87	32	24	19
16	V_{20^o}	Nm^3	required fresh air volume per kg water (= $M_{Tr/\beta 1}$)	73	27	20	16
17	N_{20^o}	kW	required fan capacity for 1000. kg H_2O/Std hours dryer capacity.	25	9,2	6,9	5,5

The energy advantage of dryer with higher temperature according to Thoma(53)

TABLE 3.

He clearly illustrates the advantages of drying with high temperatures **[Table 3]** as well as the effect on the heat consumption of various product residual moistures on leaving the dryer and the effect of using different hot air temperatures.**[Table 4.]**

HEAT CONSUMPTION FOR VARIOUS RESIDUAL MOISTURE LEVELS AND HOT AIR TEMPERATURES					
	Temperature of hot air in degrees C	60	120	150	180
	Chamber temperature = temp of clay surface in ^{O}C	40	51,5	55,5	58,5
	rel. humidity in %	38	42	44	47
4% residual moisture	Heat consumption in kJ/H_2O expelled	5200	3800	3580	3430
	Saving by drying with hot air at 180°C compared with hot air at 60°C		34%		
	Chamber temperature	44	56,5	60,5	64
	rel. humidity in %	28	32	33	34
3% residual moisture	Heat consumption in kJ/H_2O expelled	6550	4100	3800	3630
	Saving by drying with hot air at 180°C compared with hot air at 60°C		55.4%		
	Chamber temperature	51	66	71	74,5
	rel. humidity in %	16	18	19	20,5
2% residual moisture	Heat consumption in kJ/H_2O expelled	12000	4870	4350	4000
	Saving by drying with hot air at 180°C compared with hot air at 60°C		66.7%		
	Chamber temperature	60	78	83,5	88
	rel. humidity in %	8	9,5	10	11
1% residual moisture	Heat consumption in kJ/H_2O expelled	---	6440	5220	4650
	Saving by drying with hot air at 180°C compared with hot air at 60°C		66.7%		

The energy advantage of drying to the ideal residual moisture level. Thoma (53)

TABLE 4.

In 1992 Junge[99] produced three Enthalpy-moisture diagram according to Mollier (also termed 1 + x,x or h,x) as follows:

h,x-Diagram for air temperatures up to 200°C

h,x-Diagram for air temperatures up to 400°C

h,x-Diagram for air temperatures up to 700°C

The reason for producing these, according to Junge, is the fact that modern dryers exceed the relatively low temperature, moisture range diagrams usually provided in standard literature.

CHAPTER THREE

"THE STATE OF THE INDUSTRY"

3.1 SUMMARY

This section offers a brief overview of drying and dryers in the heavy clay industry. The traditional methods of drying are listed and various innovations are recorded.

Much of the information is generated from the suppliers of equipment to the heavy clay industry.

3.2 DRYING AND DRYERS IN THE HEAVY CLAY INDUSTRY

Reference has been made to Junge's contention that, within the heavy clay industry only tunnel and chamber dryers are of significance. However open air drying is still practiced on a wide scale, in South Africa. A modern reference is Stahl[24] and older references which cover early and third world practices are Clews[34] and Searle[100].

3.2.1.Open air drying.

After extrusion the wet bricks are packed onto barrows and are carted to hack lines **{APPENDIX 3.1}** which are often long narrow (250mm) strips of cement. The bricks are stacked in open formation between 8 and 10 bricks high, depending on the stiffness of extrusion. In frosty climates the hack lines have to be covered at night and in all climates must be protected from rain. When they have dried, which can take a matter of days or weeks, depending on the climate, they are once again loaded onto barrows and are taken to the kiln for firing. A less labour intensive method of drying is the use of forklifts or similar mechanisms to take open-set pallets of bricks into the yard. **{APPENDIX 3.2}** This eliminates a double handling of the bricks because the bricks dry on the pallets and are not packed on and off the hack lines. An economic balance has to be found between the density of the setting on the pallet, the drying time, the frequency of travel of the lifting mechanisms, the distance travelled and the space required to stack the pallets. A more recent development in open air drying is the use of the Dutch "HULO" or A.V.H. pack which can be dried with or without a pallet. **{APPENDIX 3.3}** It has the advantage of being a stable pack, only two bricks wide (450mm) about 2.200 metres long and is usually stacked about 13 bricks high. A good example of this may be found at the Sterkfontein Works at Olifantsfontein. If a pallet is not used it is possible to pack the dry stack directly, without repacking, into a clamp. Even more recently the "Mac Donald" pallet has proved to be very successful. It is similar to the Hulo pack but is three bricks wide which, without reducing stability, can allow vertical flues to be evenly spaced across the pack. More bricks are thus loaded on a pallet but the drying time is much the same as the Hulo pack. This pack is referred to later.

3.2.2 Hot Floor Dryers

The bricks are stacked onto floors which are hot air or steam heated. The floor of the dryer is often the roof of the kiln and is dependent on the inefficiency of the kiln insulation for it to function. This method is not necessarily labour intensive if stillages are used. This method is rarely used nowadays.

3.2.3 Chamber and Tunnel Dryers

Artificial dryers are usually divided into two broad classes, chamber dryers which are a batch process and tunnel dryers which are continuous. In the latter, ware is set on belts or cars which pass through the dryer. The terms are not definitive as the chamber is often loaded with cars and the tunnel dryer is often not operated continously over 24 hours or even over weekends. In both types of dryer the ware can be set on pallets or cars or on stillages in layers. A major development in drying was the corridor dryer of Messrs. C Keller GmbH & Co. KG with which they combined a handling system. The bricks were spaced on two parallel laths. These pairs of laths were then placed in columns and rows in a setting frame. This "module of laths" is transported with a finger car to corridors with ledges on the sides of the walls, to support the extremities of the laths. This system is well suited to bricks and all sizes of hollow ware. **{APPENDIX 3.4}**

Perhaps a simplistic and yet helpful statement of the essential difference between the two classes of dryers is the fact that, for efficient drying, temperature and humidity must be varied and controlled to suit each stage of the drying process. These parameters can be accurately controlled and varied during the drying cycle in the chamber dryer whereas in the tunnel dryer the temperature and humidity must remain constant, at all times, in any particular position in the dryer. The drying condition of the ware varies as it passes through the tunnel. Most tunnel dryers operate on a counterflow, air/ware, system but according to Stahl(24) it is advantageous to operate a concurrent flow at the beginning and a counterflow in the latter section of the tunnel.

Timmers(101) and Heitink(102) have produced two papers which seek to compare the running costs of tunnel and chamber dryers, however the comparisons are inconclusive.

Wagner(103) has a realistc approach in arguing that the choice depends on the product range and the mode of operation. He assumes waste heat is available from the kiln and argues that it should be used continuously and that the system should be simple in operation.

Riedel(104) makes a detailed study of the relative costs of operating tunnel dryers with, and without car reserves.(Reserves of cars are necessary if extrusion is not continuous and stocks have to be built up to feed the dryer, either overnight or over weekends.) Reidel opts for continuous operation and a 64 hour reserve to suit German industrial legislation.

3.3 THE STATE OF THE INDUSTRY

The state of the heavy clay industry with regard to dryers in South Africa, Europe and the U.S.A. tends in the vast majority of cases to be conventional chamber or tunnel drying. In the more sophisticated, capital intensive, plants the tunnel dryer and tunnel kiln use the same cars for drying and firing the bricks. Using this method the bricks are set once and off-loaded once, during the production process.

The following are random examples of factories built in the last few years, indicating presently acceptable production criteria. A new plant was installed at Briqueterie in Belgium with a drying cycle of 72 hours, also in 1989 the Steenfabrieken Nova installed a new plant with a tunnel and chamber dryer, the latter having a drying cycle ranging from 45-60 hours. A quotation from Hans Lingl GmbH in 1990, offered a dryer with a heat energy requirement of 3970 kJ/kg water evaporated. In 1990 Lingl supplied a new factory to Prestige Brick, Western Australia with a tunnel dryer drying in 50 hours. In the ZI International of 7-8 1992 a report on a new plant installed near Ascaffenburg claims a 22 hour drying time for a slotted jet walled Keller Dryer. In October 1992 the same journal reports a new factory built near Brandenburg with a 24 hour drying time. This is the state of the industry.

3.4 "INNOVATIONS"

3.4.1 INTRODUCTION

Under this section various projects are listed which may or may not have found favour at time of publication. A typical example is a report in the Brick & Clay Record of June 1974. It states " Brick and wall components were dried in one-tenth of the time using a newly developed drying device. The unique device uses pre-heated steam, instead of hot air. In addition to the shortened drying time, rejects have almost been eliminated." Attempts to establish the source of this report were unsuccessful.

3.4.2 "ONE HIGH"

Shaw [(105)] reports that in 1959 Rogovoi of the V.V. Kuibyshev MISI Institute, published an article (Stroitel'nye Materialy, No.9, 1959) which suggested that the best method of clay preparation, particularly with clays containing stones, was to convert the clay into a slip and then spray-dry, add additives and very hot water before extruding at some 80^{o}C. Rogovoi then used single course drying and firing. The drying time was seven hours and a six hour firing time. Research into this project was discontinued in the Soviet Union and an Italian firm built a double-course kiln whose total drying and firing time was 10 hours. This factory produced 45 000 6-slot bricks per day or 16 million per year.

A report in the British Clayworker(106) records one-hour block drying (in 1972) with a simple tunnel fanning air in at one end and sucked out at the exhaust. This factory, Fornaci Tempora Betolle, is near Siena. Admittedly this is described as an "easy clay".

In 1966 the "Rathole" project, which is the same as the "One-high" concept referred to above, was built by the Boren Brick Co in the U.S.A. General Shale implemented the total concept which produced 90 000 bricks per day, dried and fired "one high" with a 12 hour drying time and an 8 hour firing time. It was possible to reduce the firing time to between 5 and 5,5 hours. In 1972 the Brick and Clay Record carried a report on the General Shale Products "one high" plant at Knoxville, Tennesee, after 5 years operation.

The ITO technology of Fuchs, described by Stefanov(107), which is conceptually similar to the "rathole project" is an idea which is closely allied to the thrust of this paper. It has struggled for acceptance other than in Eastern Europe and only in the last two years, after the company had been incorporated into a larger corporation, have the years of consistent advertising brought acceptance of the concept. This has resulted in further development and considerable improvements in firing and drying times. ITO now claims to dry and fire from between 8 to 16 hours. The energy consumption for drying and firing is 1881 kJ/kg burnt product.

3.4.3 Dryers with a difference

In 1974 Riedel(108) developed the Riedel-Kreis-Band-Trockner system for drying bricks. It was basically a continuous belt spiralling up and down within a cylinder. In 1976 Reidel(109) invented the "Zig-zag drier" in an attempt to reduce the heat required by chamber dryers which he claimed used 20-30% more heat than tunnel dryers. He proposed the interconnection of the chambers so as to form a closed circuit. Huthmann[110], wrote a paper which criticises Reidel's Zig-zag dryer.

The CGS (Countercurrent-concurrent dryer or "Counterflow-parallel flow") dryer, is described by Weixelbaumer[111]. It is a proposed conversion of conventional tunnel dryers resulting in the use of a low volume of air and a "highly saturated" exhaust. Huthmann points out that the Moller-Pfeifer dryer of 1910 was possibly the best concurrent dryer of the century!.

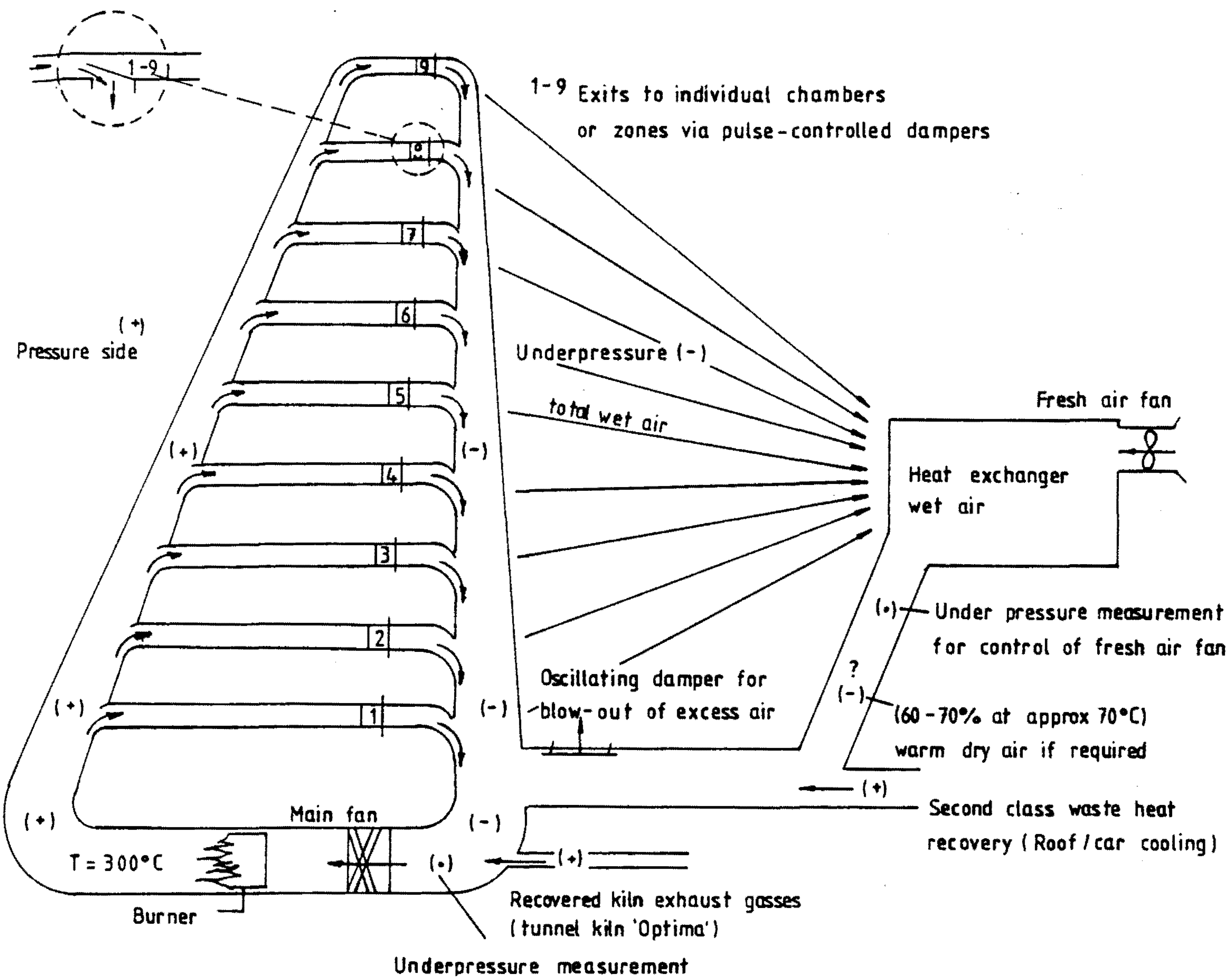
In 1976 Leisenberg[112] reports on his "jet dryer" where the ware was placed on a conveyor belt and kept at 60°C and exposed to jets of air on the "Rhythmic drying" principle. A drying time of 2-3 hours was claimed. Discussion with his engineers revealed that considerable problems had been experienced with the conveyors and these dryers are no longer sold commercially.

In 1977 Smolski[113] reports on and provides diagrams of the "SG model fast dryer". The extruder and dryer form a unit. The bricks were ultimately extruded at 75°C and took 15 seconds to be placed in the dryer. He records temperatures in the dryer of 75-130°C. The damper is fully throttled to produce superheated steam within the dryer and a 3 hour drying time was achieved. It was planned to build a full scale plant in Poland to dry 35-40 million units per annum with a drying temperature of 140°C. The extruded column temperature was 80°C, with a specific heat consumption of 3553-3702 kJ/kg water.

In 1978 Bradstock[114] reports on a "soft mud" dryer, drying in 18 hours, with a damper system in the walls which seems to be similar in concept to the Keller dryer wall-jet-slot system which they have developed in recent years.

Nieberding[115] has patented the "INTEGRA" system which pulses a predetermined amount of high velocity hot air at constant velocity and constant temperature into the drying chambers, which have recycling fans.

He claims that it is now possible to use hot air at 300°C as against the previous temperature of 150°C to considerable advantage.



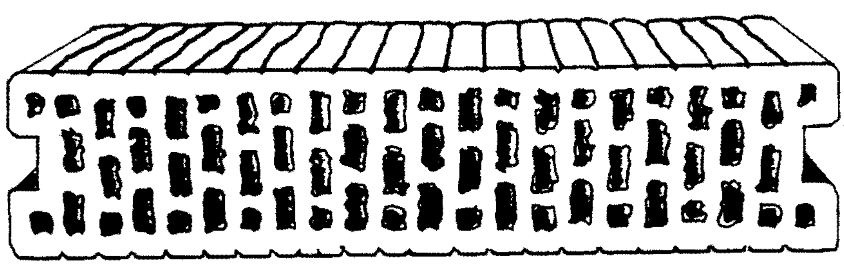
Hot Air Velocity > 20 m/s   Air temperature approx. 300°C   Air volume, twice that required

A schematic representation of Nieberding's "integra" system (115)

FIGURE 8

Using air to air heat exchangers he works the following example: The 10kg of air added at 300°C will evaporated 1kg of water and this will have an energy content of 3000kJ. The air on the wet side will have 10kg of water vapour at 80°C with 3000kJ available for use. Passed through an air/air heat exchanger he claims that 6-7 kg of hot air at 75°C plus 50% of the water at 65°C. will be produced, which is very attractive.**[FIGURE 8]**.

Wagner(116) (1993), argues for faster drying and firing to reduce capital costs. He says that traditional drying was directed at bricks and blocks with small perforations and consequently only small increases in drying rates were experienced with vertical coring blocks. The reason given was that the traditional methods did not efficiently penetrate the inner surfaces of the perforations. While the latter statement may be true the Italian transverse holed blocks have always had large holes or perforations. A typical block, targeted by Wagner, is shown in **[FIGURE 9]**. This block has holes that are smaller than the typical Italian block.



A typical hollow block

FIGURE 9

In 1979 the prototype of the "System Strohmenger"(117) was reported in the ZI International of July 1979. It appears to employ hot extrusion and has a specific heat consumption of 3561 kJ/litre water extracted. No drying times are given. Stromeyer(118) also developed a hot-air jet system to reduce the possibility of "air pockets".

In 1987 Imas SpA(Italy) patented a system[119] for drying tiles in 5-6 minutes as against the conventional 40-60 minutes for the same product.

Novokeram have decided to develop a fast dryer that aims at an even air-flow over all the block surfaces, within and around the block. They have had success in drying 1,3 metre long catalyzers with 80% cavities within 32-38 hours with intractable clay. Following this success they dried 2 perforated blocks in succession in 45-65 minutes without recirculating the air. After this they dried bricks 2,8 metres long in 10 hours which were stable and crack-free. It is assumed that these were also hollow bricks. In this plant 5 successive cored blocks were dried "in an amazingly short time". This penultimate experiment was also reported by Wagner[120]. In this same paper he reports that in their portable test plant they were able to dry a wide range of sizes of bricks, without cracking, in 50 minutes. He goes on to report that varying raw materials, the shape of the coring and the type of aggregates used, or their proportion, had no influence on the drying.

A test plant was designed which would simulate industrial conditions. He says that in addition to the aerodynamic concept, the subsidiary questions of uniform air distribution and optimum brick or block setting had to be established.

It would seem that Novokeram have abandoned the rotomixair unit design in favour of cross-flow fans and baffles, for greater economy. The balance of air-flow through the block which is balanced with the air-flow around the block is reminiscent of Kother's[67] paper in 1979. The problem of an asymmetrical perforation pattern creates air-flow problems. The number of bricks/blocks in line had an important bearing on the drying results and a reversal of air-flow was found to be necessary. This was to be expected from the contents of previous papers quoted above. With non-reversal of air-flow the first brick dried in 90 minutes and the fourth brick requires 5 hours while with reversal of the air-flow a successful drying was achieved in 4 hours. Wagner believes that within a year, i.e. by January 1994 a successful industrial dryer would be possible.

3.4.4 Steam drying.

According to Bergholtz[121] steam drying can be divided into three pressure ranges, underpressure(vacuum drying),normal pressure (superheated steam drying) and overpressure (superheated steam- overpressure drying). He selected the overpressure range for an experiment. From Stefan's Diffusion Law it is obvious that both temperature and pressure effect the evaporation rate of ceramic bodies. Comparing "evaporative" drying against steam drying he states: "With evaporative drying the reduction of the drying rate after reaching the first break-point in the drying curve is conditional on the diffusion resistance. The evaporating water has to cover increasingly longer distances via air-filled pores.

He concludes that for evaporative drying the external drying conditions are determined by, temperature, relative humidity and flow rate,in steam raising drying only temperature and absolute pressure have an effect. Finally that,in industry,the advantages of steam drying can only be partially achieved.

In 1992 Stubbing and Ford[122], (Ford is with British Ceramic Research Institute), produced a paper on "Airless Drying", and refer to the drying medium as superheated steam. They have patented the dryer in the U.K. and have applied for patent rights in 16 countries. The Airless drying method won the 1989 Sunday Times/Honeywell British Innovation Award for Manufacturing Technology. The principle seems merely a combination of humidity drying with internal heating and heat recovery from the exhaust hot wet air and the climatics dryer referred to by Stahl[24] above. For the following reasons it is difficult to understand how this dryer has been patented. The Brick & Clay Record report referred to above seems to have used the same principle in 1974 and Smolski used superheated steam and dried in three hours which is certainly better than Stubbing and Ford. In 1991 Lingl[60], quoted above, remarks that in the preheating stage their dryers do not add hot air but reheat and recirculate the air in the chamber.

CHAPTER FOUR

THE INDUSTRY IN SOUTH AFRICA WITH PARTICULAR REFERENCE TO THE WESTERN CAPE.

4.1 SUMMARY

This chapter deals essentially with the minimisation of cost, not only production cost but capital cost and so called "hidden costs" such as the desirability and often need, in this industry, to provide housing for employees. It also faces the challenge of optimum plant utilisation and the need for a plant with the appropriate level of sophistication for the required function.

Cognizance is taken of current practice in the South African brick industry where many factories have state of the art crushing and preparation equipment and yet beyond the extruder use methods of drying and firing which are labour intensive, subject to weather conditions and are not subject to production control. At the other end of the spectrum there are the sophisticated, capital intensive plants which are comparable to American and European standards. It will be shown that this latter capital cost and level of sophistication is not justified, either in South Africa, or even in the most highly developed countries.

It is desireable that a solution to the former be found which does not require a capital intensive route. It should in fact be possible to dry with an low overall capital investment, possibly comparable running costs and all year production. Wastage, which is a problem (12 -20%) in less sophisticated plants, must be reduced. A flexibilty, which allows increased production during peak demand times, without the need for additional plant must be an alternative. It is further shown that the so-called sophisticated plants are not only relatively capital intensive but may also be wasteful of construction materials and require qualified technical maintenance staff. In this latter case less expensive plant is proposed, which is technically simpler and

lower in maintenance costs, requires much the same labour complement to operate, allows production flexibility as above and compares favourably in specific energy consumption and drying waste.

In conclusion it also examines the potential of converting the entire NFP and solid maxi brick production in South African factories to similar sized hollow-ware. This latter aspect will be proven to make the greatest single contribution to the aim of this paper, namely, the reduction of energy consumed in the industry and the specific energy consumption, in the dryer, per unit. It will reduce the use of clay, a non-renewable resource. Production costs per unit will be reduced with it's subsequent effect on the cost of building and low cost, or "affordable", housing in particular.

4.2 A SPECTRUM OF SOUTH AFRICAN BRICK FACTORIES.

4.2.1 Production Method One

This method is descriptive of a brick factory with adequate raw materials handling and clay preparation plant. The well mixed clay, usually with a particle size of less than 4mm, and the fuel additive are deliverd by conveyor belt to a de-airing extruder at which point the required water for extrusion is added. The extruded column is usually cut with an automatic single cutter of the Keller or Brunetta type or a multiple cutter most typically a Steele Reel Cutter. The bricks at a rate of from 4-15,000 an hour are then set by hand on to wooden pallets.(A typical labourer, working on an incentive bonus scheme, packs 1,300 bricks an hour in a particular Western Cape factory.) These pallets are mechanically transported into the drying area where they are open-air dried. When the bricks are sufficiently dry the pallets are then transported to the kiln area were they are packed and fired. This typical brick factory producing common and semi-face building bricks depends entirely on open air drying and more than likely, other than in the Eastern Cape, on Clamp firing. This is the worst method, from a production point of view, where, in the Western Cape, the brick factory often operates for seven or eight months of the year, due entirely to weather constraints. These weather constraints govern drying and to a lesser extent clamp firing. The latter, weather dependency problem, can be solved by using a concrete slab with simple inexpensive sheds, or mobile sheds, as well as the judicious use of shade cloth screens.

4.2.1.1 Clamps

Clamp firing is associated with minimal capital outlay, if the capital cost of the transport mechanism for moving the dried bricks to the clamp is ignored, the only cost is the preparation of the ground on which the clamp will be built. Where clamps are fired in winter either fixed or mobile sheds are often built to facilitate packing in the rain and also to reduce rain damage to the bricks during the firing process. These sheds represent a capital cost which would be common to any kiln, although a clamp kiln shed is structurally inferior to, and cheaper than, a building for any permanent kiln. As stated above the clamp method of firing bricks is not weather dependent, to the same extent as external drying.

"Clamp yards", as they are referred to in the industry, are labour intensive, have a high wastage and because of factors such as varying wind velocity and direction, cannot be well controlled. Clamps are a source of air pollution.

Waste heat is never recovered from clamps and a fuel consumption of 3570 - 4200 kJ/kg is quoted by Smalzried and Bender (APPENDIX 1.2) Huiras[123] quotes a range of South African figures from 1700 - 3400 kJ/kg. Consumption figures of 2000 kJ/kg in the Western Cape, which are better than Smalzried and Bender and at the bottom of Huiras's range, are still not economic when compared against some tunnel kilns. Further, Huiras quotes 14% as a reasonable waste figure for clamps. A survey done in 1990 by the Clay Brick Association of South Africa, on 18 South African Brick factories making 4,9 billion clamp bricks a year, records 10,42% average waste in the drying and kiln packing process, and a further average of 11,75% at the clamp unpacking stage. Joostenberg Brick, at Muldersvlei, has an average production waste, determined over 21 years, of 12%. This implies an additional energy waste of about 240 kJ/kg.

4.2.1.2 Weather conditions have a primary effect on outside drying.

In the Transvaal, frost is a problem which can be controlled by covering the bricks at night, while in the rainy season, thunderstorms can wipe out the entire production standing out in the yard. Even if these bricks are covered, covering can be inadequate protection against a Transvaal thunderstorm. In the Cape, during the wet winter season, humidity is high, causing a typical stack of some 450 bricks on a pallet, which would dry in 7 days during summer, to take many weeks to dry, providing that it could remain uncovered for that period. which is not the case, In 1991 humidity in the Western Cape remained uncharacteristically high up to the end of October and this adversely effected production, in brick factories using open air drying. A longer drying time requires a larger prepared area for stacking, longer travelling distances and therefore additional capital expenditure on forklifts, as well as additonal drivers, who have to be housed.

Physical rain damage is a far greater hazard than high humidity, to the brickmaker who dries outside, because his entire production or at least some part of each stack can be destroyed. This means, if there is partial damage, not only that he loses some bricks, but that he has to remove the damaged bricks so that the remaining bricks on the stack have a better chance of drying. If the stack has collapsed he has to remove the bricks and recover the pallet from under, what has become, a heap of mud. The technique of using forklift clamps on the bottom layer of bricks, rather than a wooden pallet, and then, placing the stacks on concrete strips, similar to the old fashioned hack lines, is a method perhaps even more susceptible to rain damage. The reason for this is that the bottom layer is in contact with the ground and so it is likely to be the first to get really wet and collapse under the weight of the rest of the stack. Another problem is that even on well-compacted and well-drained surfaces, forklifts damage the wet surface, with the attendent problems of having to transport the new stacks over, and set them down on, an uneven surface. This causes damaged to the newly stacked bricks and introduces a waste component even before drying starts. In the Western Cape the decision has to be taken when to stop placing bricks outside, in the yard, at the beginning of winter and when the factory can safely, restart production after winter. When bricks are exposed during periods of potentially inclement weather a balance has to be struck between the cost of covering and uncovering the stacks against the advantage of having open stacks exposed to slightly better drying conditions, even for a few hours. (One factory in the Western Cape has lost 1,3 x 10^6 bricks, in the drying stage, during one year.) Clay is hygroscopic and the bricks are adversely effected by absorbing dew or being wet by light rain which can cause fine cracking on the exposed brick surfaces. In the Cape, even during the dry summer months when the "method one" brickmaker has more bricks outside than he can cover, his entire production, in the yard, is at risk and could be wiped out by an unseasonal storm or perhaps 50-75mm of rain. Typically this implies putting in the order of, 1-2 million bricks at risk, as well as the delay and the possibility of having a period when there are no bricks for sale. **FIGURE 10** gives an indication of damage to a pallet of bricks which was exposed to 107 mm of rain, from 9th-13th April 1993. **{APPENDIX 4.1}**

Square pallets, at Claytile in Koelenhof ,these bricks had been made and set on the day before the rain

FIGURE 10

4.2.1.3 The transport of pallets and brick stacks.

Rectangular stacks of about 450 bricks are set either automatically with expensive (A capital cost exceeding R1 000 000) relatively sophisticated, high maintenance, setting machines, or by hand. (Only one factory, in the Method One catergory, in South Africa, at present, uses automatic setting.) These rectangular stacks are usually set on wooden pallets and can be transported by forklifts or inexpensive tractor/lift modifications to the drying yard.**{APPENDIX 4.2}** The "Hulo" pack referred to above is an oblong stack of about 700 bricks each and because the stack is narrow the bricks dry more quickly. This stack can be used with or without wooden pallets as referred to above. It has the advantage of carrying more bricks per load and this implies fewer journeys. A disadvantage, from the automation point of view, is that, because the setting pattern is complex and the fact that most setting machines available on the market need to have brick/block multi-purpose applications, there is at present, only one Dutch firm which produces this machine and there are none operating in South Africa. The additional load is too great for the "tractor modifications" available and so the forklift best suited to this work is the South African developed Bell three wheeler.

While the Bell can carry a heavier load it does in fact not match the speed, particularly on the return journey, of the modified transporters. A 4 tonne Bell, Model FL 220, costs R149 000 (February 1993) and this is more expensive than the modified tractors which can be built up from used equipment. (These modified tractors are hardly a fair comparison, but an alternative readily available to the privately owned brick factory, and therefore this option is cited). The Bell FL 220 also permits the use of the clamp stacking mechanism.**{APPENDIX 4.3}** The Bell FL 220 is used as the basic unit for the cost calculations in this paper.

4.2.2 Production Method Two

This method encompasses a group of brick factories that are virtually the same as Method One but with essentially one major difference. These factories have a dryer. They may operate the dryer throughout the year or only during the wet season. These factories operate either Chamber or Tunnel dryers. All pack by hand, either onto a pallet, for the chamber dryer, or directly on the dryer car. When the brick is dry enough for packing into the kiln, the pallet or the dryer car is transported mechanically to the kiln area where the bricks are re-packed ready for firing.

4.2.2.1 Factors effecting production.

If these factories make adequate provison for clay handling and preparation during the wet months, then, apart from the effect of the humdity on the drying process, there should be little difference in the volumes of wet and dry season production. Weather obviously does not effect the process to the same extent as described in 4.2.1.1 above, although there are some inconsistencies due to weather particularly in plants which dry outside during the dry season. There is still the double handling problem, where the bricks are packed onto the pallet or car for drying and then again from the pallet or car into the kiln. In both Methods One and Two, in excess of 90% of the production being discussed is packed into clamps. Clamps are essentially a solid stack of bricks comprising from the smallest of say 50 000 bricks to some clamps which contain 6 000 000 bricks. **{APPENDIX 4.4}** As against the practice of solid stacking in the clamp, for drying, bricks are always stacked in open configurations for easier air-flow to facilitate evaporation.

4.2.2.2 A variation in clamp stacking.

Although the following concerns a variation in the clamp stacking method, it must be mentioned for completeness. This method is a way of eliminating the double handling referred to above. It is possible to transfer stacks from cars or pallets directly into a clamp, using clamping mechanisms on the Bell FL 220 or any other suitable forklift. Corobrik at Koelenhof, in the Cape, take stacks directly from the dryer and previously at Paarl, from drying in the open air, and set them, in open configuration, in the clamp. **{APPENDIX 4.5}**

It is not appropriate to discuss the reasons, in this paper, why this method of firing clamps has not found general acceptance in the brick industry in South Africa.

4.2.3 Production Method Three.

This method represents the third group in the continuum of typical brick factories. This group usually has slightly more sophisticated, even if not justifiable, materials handling preparation and extrusion plant. These factories usually operate Tunnel Kilns and set the bricks either automatically or by hand onto the kiln car which then goes into a tunnel dryer for drying before being transferred to the Tunnel Kiln for firing. In these cases the stacking configuration is designed so as to be optimum for both drying and firing. The stacking may, or may not, be done with an automatic setting machine. This whole operation takes place under cover and need not be effected by weather conditions. The double handling referred to above in both Method One and Two is not applicable in this case. The criteria which are of greatest concern in this case are an over-capitalisation, the sophistication of plant, as well as excessive management, maintenance and often running costs.

4.3 AN INDICATION OF FUEL CONSUMPTION AND DRYING TIME IN TYPICAL SOUTH AFRICAN DRYERS

In a private communication, John Arnold & Co of Johannesburg, reported the following drying times and fuel consumption in three South African Dryers, the figures were provided by the factories concerned, and corrected for grade A coal:

No figures are available as to residual moisture but assuming 5% as reasonable and assuming that on average 500g of water are removed from each brick. Then, ignoring Meyerton Brick, we have an average of 100kg of Grade A coal to dry 1000 bricks. This implies 5600kJ/kg evaporated water.

This was the energy consumption, excluding electrical energy, in a sample of typical South African dryers, taken at random.

Factory	Drying Time	kg coal per thousand
Federale Stene -Middelburg	48-55 hours	130
Cullinan brick -Midrand	40 hours	116
Meyerton Brick	48 hours	34
Western Cape Factories		
Corobrik -Koelenhof	72 hours	80
J & J Brick -Kalbas Kraal	30 hours	100
Joostenberg Brick - Muldersvlei	36-48 hours	74

Typical drying times and coal consumption for six South African Dryers.

TABLE 5

4.4 CAPITAL COST OF DRYERS.

In July 1990 quotations were called for, to dry 100 000 bricks per day. The dimensions of the brick were 106mm x 73mm x 222mm, with a fired weight of 3,2 kg each holding 600 g of water in the green state.

Brickequip (Pty) Ltd, representing CERIC of France, submitted a budget quotation of R3 000 000 for dyer equipment only. A fuel consumption of 4190 kJ/kg of evaporated water was guaranteed.

Ceramics and Technology, representing Hans Lingl of Germany, quoted approximately R 1 890 000 for drying equipment, excluding erection and commissioning. A fuel consumption of 3980 kJ/kg of evaporated water plus 140KW of effective electrical power.

A. Huiras - Interceram (Pty) Ltd, in a private communication, expressed the opinion that there is considerable scope for the improvement of the efficiency of brick dryers and he regards this as the most neglected area of brick making. Huiras believes that R 4 000 000, which includes the mechanical handling system, would be a realistic figure to build the above dryer.

4.5 THE CHALLENGE

The need was in fact to improve the situation in all three methods of production, referred to above, from a cost and if possible an energy effective point of view. Quantitatively, the production parameter decided on was 15 000 bricks an hour as an upper limit.(140 000 bricks per shift).

4.5.1 The first requirement

This was to bring Production Method One up to the production level of Production Method Three which is often, because it has no weather constraints, more consistent over a 12 month period than Production Method Two. This implies that production must be consistent over a twelve month period and must not in any way be effected by the weather. Obviously there are the advantages of fuller utilisation of plant and consistent requirements of labour with the easier implementation of incentive bonus schemes and therefore consistent earnings as against a drop of earnings over wet periods. It used to be practice for seasonal brick factories to pay labour only during production periods but allow them to live on the premises throughout the year and do casual work if they could find it. In legally and correctly operated Production Method One factories, the labour is retained on full pay during non productive periods, doing general maintenance and cleaning, but as mentioned above, are unable to earn any bonuses during the wet season. This is a very expensive exercise.

4.5.1.1 An analysis of the production figures of a Western Cape factory.

The analysis, over 10 years, of a "Production Method One" plant operating in the Western Cape, indicates the potential gains which can be effected by eliminating weather as a production constraint.

- In the first instance a variation in monthly production due to factors like an "early wet season", a "late wet season" or the phenomenon mentioned above of high humidity late into the dry season, as well as "unseasonal downpours" caused variations in production of 3×10^6

bricks per annum(from 12-15 x 10^6 bricks per annum), during a ten year period at the one particular factory.

- A second factor which can be included under this head is wastage due to "unexpected" rain damage. In some years this has accounted for a loss of 400 000 bricks in the drying stage of production. Here again it is not only the loss but also the clearing and pallet recovery costs which have to be met.

To quantify, this means at worst a potential loss of 3 x 10^6 bricks in one year without any reduction in fixed costs, plus the need to remove and reprocess, at worst, 400 000 bricks which had already been partially dried. Using a 1991 Balance Sheet as a basis for calculation this implies a pre-tax loss in profit of ~ R 350 000 in one year. Here the assumption is made that a "good" season does not imply additional costs and the argument hinges on being able to accommodate the unexpected, as well as the availability of sales. As stated above, the labour is at the factory in any case and the plant is started up to, at least, produce a few bricks in the wet months and so the maximum demand for electrical costs is normally registered, and paid for, each month.

4.5.1.2 The loss of potential production.

In two factories under survey, the loss of production due to the inability to produce during the wet months, because there was no dryer, was in the order of 8.6 x 10^6 bricks at the one factory and 6 x 10^6 bricks at the other. Calculated on the same basis as above, but including variable costs, this implies a pre-tax loss value of some R 800 000 and R 570 000 respectively. In the case of the Western Cape, the wet season is indeed a fact and therefore additional costs need to be incurred to construct and operate a dryer.

4.5.1.3 The handling cost.

The cost of the initial handling operation after the column has been cut into bricks is as follows:

- The labour cost of packing the wet bricks onto pallets by hand, including driver costs is R4 00 per thousand. (No allowance is made for housing and social welfare costs inherent in employing and housing labourers.)
- The Total Cost per hour **{APPENDIX 4.6}** of two Bell FL 220 converts to R 1.60 per thousand bricks.
- In addition to the above there is the capital and maintenance cost of pallets calculated at R 1.90 per thousand bricks.
- There is an additional cost of "work in progress" as the bricks dry in the yard for a period far exceeding that for which they would stand in a dryer.

On a monthly production of 2 x 10^6 bricks this a cost of R15 000 per month.

- Mechanical setting machines, other than brick setting machines used in the large factories in the U.S.A. which set some 30 000 bricks per hour, are able to set an upper limit of 11 000 standard bricks an hour. These setting machines set directly onto a car or a pallet. The capital cost is in excess of R 1 000 000 and paid back over 5 years would cost R24 000 per month, for both interest and capital redemption. This ignores any advantages of a residual value, the tax benefit from depreciation, or on the interest portion of the payment. The average small brickmaker is normally primarily concerned with cash-flow. If this is the case then the above lease option compares unfavourably against hand setting, at say R8 000 per month for the direct cost of labour. In addition, maintenance costs, possible downtime and sophisticated plant factors have to be taken into consideration for the setting machine.

- There are a number of reasons why the handling of bricks from the setting position at the extruder out to the yard and from the drying yard to the clamp should be eliminated. In using pallets, either into a chamber dryer, or out into the yard, there is wastage figure due to the damage caused by transporting stacked wet or even dry bricks. This waste figure depends on the terrain, the skills of the driver and the quality of the clay but three bricks cracked or damaged on every pallet would already be more than 0,6% of the set production or 12 000 bricks, per month, in the case under discussion.

A recent development by Mc Donald at Joostenberg Brick in the Western Cape is a modified "Hulo" pack which is three bricks wide, as against the "Hulo" which is two bricks wide. This pack allows vertical draft which speeds up drying in the open air, stacks 720 bricks per pallet and over a test period of a few months has reduced transport breakage to considerably less than 0,5%, due to the stability and rigidity of the stack.[**FIGURE 11**]

4.5.2 The basic premises to upgrade Production Method One.

4.5.2.1 There is a need to build a dryer.

The basic premise for the solution of Production Method One's initial problem is that a dryer is imperative.

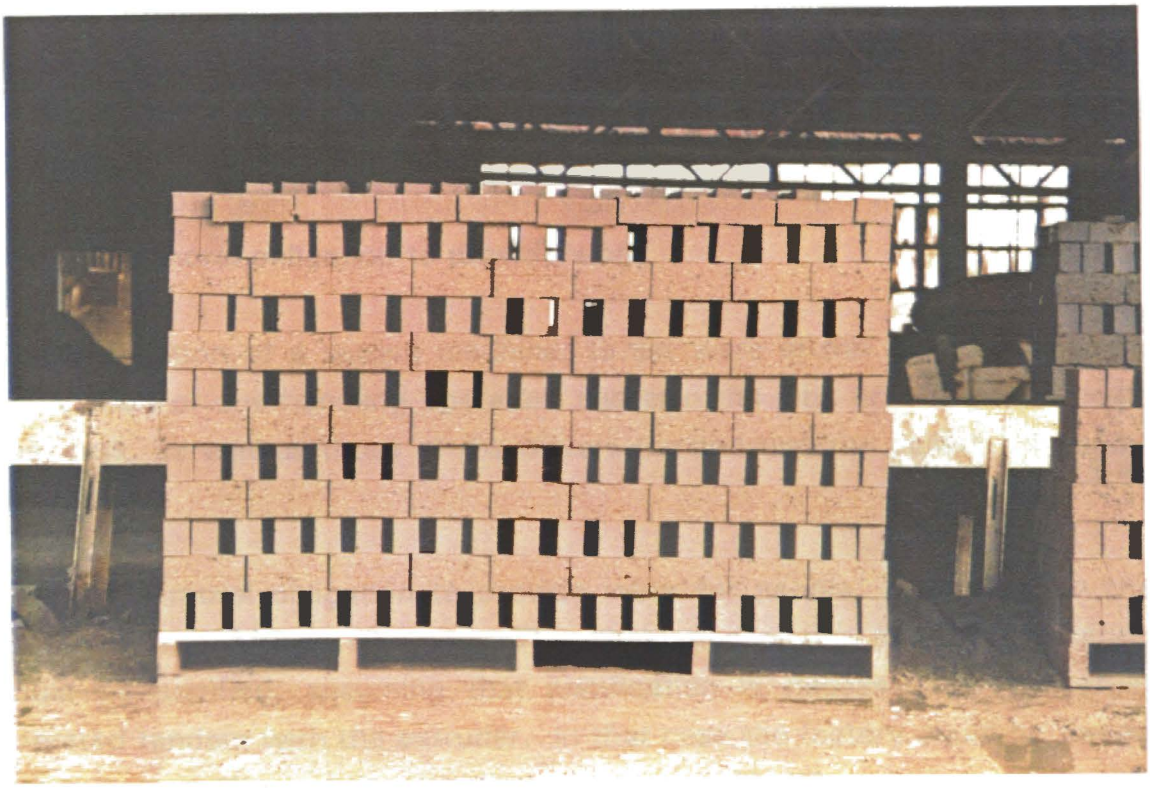
- The dryer must be able to dry the production of a plant which extrudes 15 000 bricks per hour on one shift.

- A different kind of dryer is implied, that is, different from those, with prolonged drying times, commercially available at present. Considering the literature, and recent developments, a fast dryer would seem to offer an ideal solution to the problem..

- The dryer should have a low capital cost, be low in maintenance, operating and energy cost.

- Ideally this simple dryer should be able to be assembled and fabricated on site, with readily available components.

- The dryer must be operated by semi-skilled operators.



The Mc Donald Pack

FIGURE 11

4.5.2.2 The possibility of building a setting machine

As has been noted above, transport to a drying chamber is not desireable and therefore it would be sound practice to place the bricks directly into the dryer in one setting motion.

The setting machine which would be in keeping with the thrust of this paper would have to have the following characteristics:

- It would be inexpensive to build and to operate. In fact, ideally, it should be built on site by the plant fitter.
- It would be low in maintenance and would have to have inexpensive exchange parts which could be changed rapidly by unskilled operators.
- It must be operated by semi-skilled personnel.

If such a machine could be produced it would immediately suggest a similar machine to set off the dryer to pack a solid square pack for direct setting into the clamp, with a fork-lift. This would eliminate another handling operation.

4.5.3 The moral obligation to provide work

The installation of a setting machine, to set ware in the dryer, implies the elimination of one handling operation and also the jobs of the setters doing that task, as well as those of the drivers transporting the pallets out to the yard.

There is a moral obligation to provide work for people, particularly in the present South African situation. The elimination of one handling operation could be justified, assuming that justification is necessary, if the dryer operated tandem with the extruder. In that case the factory could be turned into a two or three shift operation without additional capital cost. In this way production could be doubled or trebled, with the overall employment of more people and a better utilisation of plant. The reduction of at least one setting operation would reduce the production unit cost and the waste.

4.6. The need to produce clay hollow blocks in the Western Cape and the effect of the possibility of being able to fire hollow-ware in a clamp.

4.6.1 The challege of firing hollow-ware in a clamp.

A key issue, regarding clamps, which could effect the energy consumption of clay products, "in the wall", is the fact that it is "common knowledge" in the industry that hollow-ware cannot be fired in a clamp. Huiras[123] says that "large-size, perforated aerated bricks are not for clamp firing but rather, "Standard -size solid bricks (normal fired size = NF = 222 mm x 106mm x 73mm), perhaps with three holes, are predestined for clamp firing". Were this to be proven untrue a whole new situation with regard to the economics and competitiveness of clay products, as against cement walling, would be opened up. This is a fundamental insomuch that were it possible to fire hollow ware in clamps, all solid brick brickmakers who burn in clamps would immediately be able to produce hollow-ware, instead of solid bricks. At present the capital cost of a kiln prevents them from considering the production of anything other than bricks.

4.6.2 Characteristics of hollow-ware to be produced

4.6.2.1 Some of the advantages of hollow-ware compared against solid bricks.

Some of the advantages of hollow-ware, as against solid bricks, were set out in 1.3.1 above. Breakage's are minimal due to dimensional relationships with respect to the die and the direction of extrusion. The crushing strength required for solid bricks by the SABS specification (7mPa) is easily achieved.

There is also a customer resistance against bricks with holes, (usually three vertical holes in the 222mm x 106mm face), in them, as they are perceived to have a greater percentage of breakages on site, than solid bricks. Bricks with holes, both cement and clay, are distinctly different from the proposed hollow-ware in which the lateral holes are parallel to the ground when built into the wall.

4.6.2.2 The proposed hollow blocks

Initially it is proposed to produce two hollow blocks and then, after the market has shown acceptance of the new Inca "Jumbo 2 " cement block, to produce that as well. The external dimensions of the Jumbo 2 block are 290mm x 90mm x 155mm and it is proposed to put six holes of say equal size in the block and name it a "**WB6**"(Wall Block - 6 holes).

The dimensions of the block of normal solid brick size, are 222mm x 106mm x 73mm with two lateral holes each 38mm x 25mm. This block is called a "**WB2**". The second block will have the same external dimension as the cement and clay "Maxi brick" (222mm x 115mm x 90mm) with 4 lateral holes each 38mm x 25mm and is a "**WB4**" **[FIGURE 12]**

It should be noted that the solid brick or cement imperial, as well as the WB2, will give a 106mm single skin wall while the maxi and WB6 will give a 90mm wall this has been accepted and certainly is no cause for concern in internal walls and cavity walls. A major face brick producer in the Western Cape is about to market a 90mm wide face brick (May 1993).

TWO EXAMPLES OF THE PROPOSED HOLLOW-WARE OFFERED AS A SUBSTITUTE FOR SOLID BRICKS AND MAXIS.

THE "WB 2" (wall block with two holes) AND THE "WB4" (wall block with 4 holes) or "MAXI"

{THE EXTERNAL DIMENSIONS OF BOTH PRODUCTS ARE THE SAME AS THE PRESENT SOLID EQUIVALENTS}

FIGURE 12.

The masses of the three blocks, compared against the cement equivalents are as follows:

	CLAY	CEMENT
Solid Brick	3.2 kg	3.33 (average)
WB 2	2.65 kg	-----
WB 4 (Maxi)	2.5 kg	3.73 (average)
Maxi(solid)	-----	4.75 (average)
WB 6 (Jumbo 2)	4.43 kg	6.5kg

The masses of the various units under consideration

TABLE 6

TABLE 6 clearly indicates the mass advantage of clay over cement and suggests it's distinct advantage in productivity as a building material.

4.6.3 The rationale behind producing hollow-block in the Western Cape, particularly at the present time.

4.6.3.1 The market situation in the Western Cape.

During the past year the clay brick maxi has lost market share to their cement competitors. Corobrik is not prepared to make maxis for under R400 per thousand. Figures supplied by the Western Province Masonry Manufacturers Association indicate that while there was a decrease in sales of 11.5% from 1991 to 1992 for the clay industry, the cement industry only decreased it's sales by 3.9% over the same period.

Cement brick manufacturers are selling their maxis more cheaply than clay producers as indicated below. Prices quoted in April 1993, **(TABLE 7)** were given over the telephone and it can be asumed that if price cutting is taking place, contract prices will be even cheaper. Proof of the unstable market is supported by the data provided by Integrated Management Services for the Western Province Masonry Association, compared against the telephone quotes. These former prices are used for calculations.

	BRICKS	MAXIS SOLID	MAXIS HOLES	JUMBO 2
CEMENT				
INCA	R271.70	R300.00		R480.00
D.B.L.		R330.00	R304.00	-
D.C.M.		-	R355.54	-
Master	R257.85	R376.22	R323.68	-
Kohler	R245.00	R285.00		
AAA Steco			R362.90	
CLAY				
Crammix	R297.00	R384.00	R381.00	
Brick & Clay	R245.00			
Claytile	R230.00			
Joostenberg Brick	R225.00			

Product prices, quoted over the telephone (April, 1993), in Rands per thousand, ex yard.

TABLE 7

A further comparison was provided by Integrated Management Services. **TABLE 8** is an extract from their table dated September 1992. It will be noted that there are differences in price in many instances, compared against the telephone quotations. and they exclude reference to clay maxis.

It is estimated that 6 producers of cement maxis, in the Western Cape, are making in the order of 5 x 10^6 maxis per month. Only Crammix are making conventional clay maxis at present and have produced a clay maxi similar to the "WB 4" since the month of April 1993, this is being marketed under the name of "CRAMLIGHT" and was sold at a special introductory offer of at R360.00 per thousand. **[FIGURE 13]** shows the same product being produced at the Blake's Bricks Ltd factory at Killarney, near Milnerton, in the Cape, where it was dried in a Keller Dryer, referred to above, and was fired in a Morando Tunnel Kiln. The photograph was taken in about 1967.

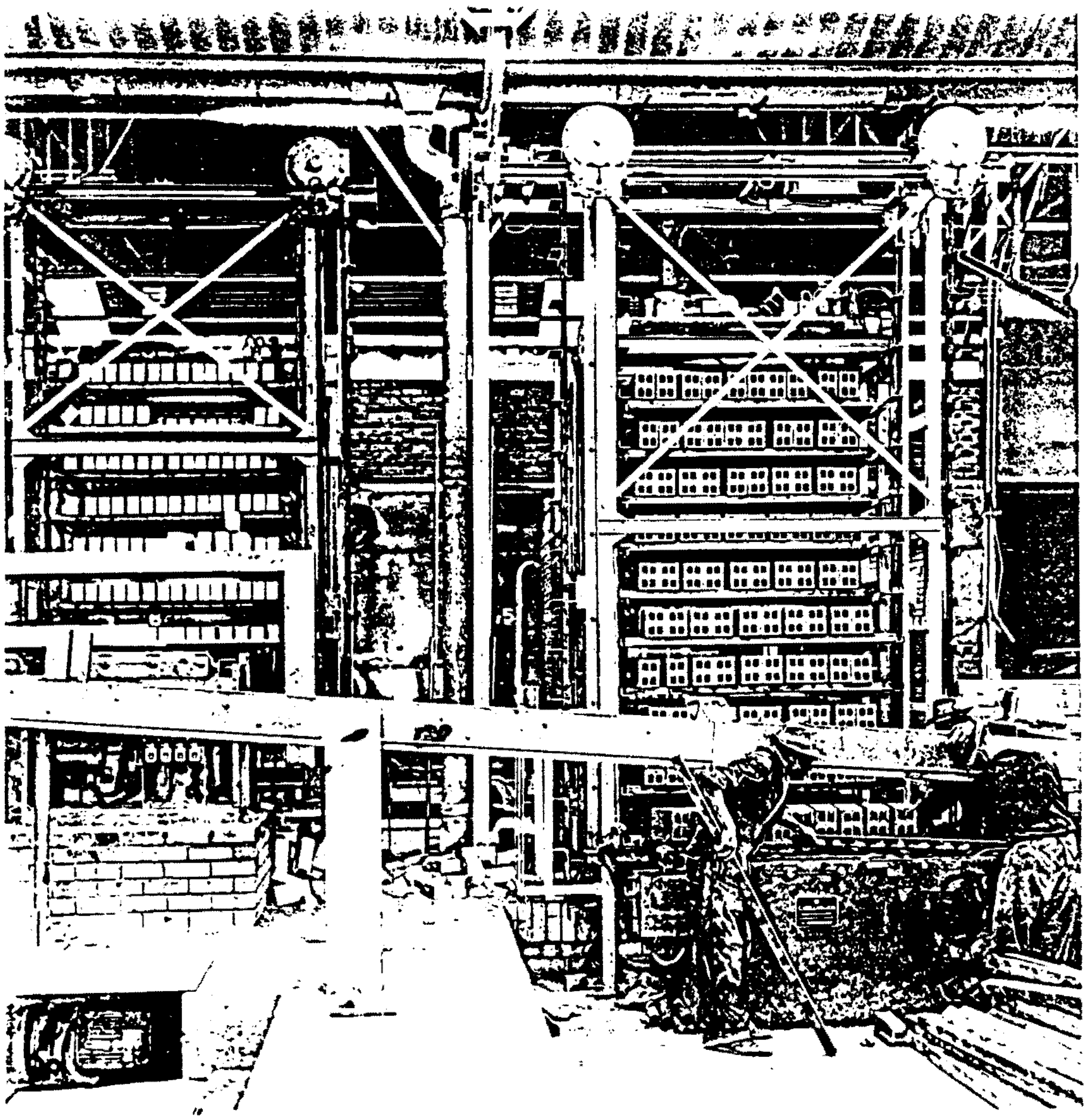
PRODUCT	Selling Price in Rands per thousand.	Cost/square metre in Rands.	Brick equivalent in Rands.	+ or - % with solid brick as the std.
CLAY				
BRICK	R230	R12.08	R230	Nil
CEMENT				
IMP DBL	R230	R12.08	R230	Nil
IMP KOHLER	R210	R11.03	R210	- 8.7%
MAXIS INCA	R316	R10.74	R204	- 11.3%
MAXIS DCM	R290	R10.00	R191	- 16.5%
- 5.2%	R275	R 9.49	R181	- 21.3%
- 10%	R260	R 8.84	R168	- 28.0%
MAXIS DBL	R278	R 9.35	R178	- 22.6%
MAXIS STECO	R308	R10.47	R199	- 13.5%
MIN.	R278	R 9.45	R180	- 21.7%

Figures extracted from a table by IMS dated September 1992.

TABLE 8

4.6.3.2 The relative cost of hollow blocks.

TABLE 9 sets out a comparison of the relative cost of hollow blocks using the solid brick and it's market price, in September 1993, of R230 per thousand, as a basis for comparison and calculation. The assumption made is that the production costs, other than maintenance and materials, will not differ between the products. One significant difference in cost would be the change in either dryer or kiln capacity due to the volume of each unit. This would be signifcant in the proposed dryer but not in a clamp kiln, other than for an adjustment for a difference in the mass of coal in the scannels.



Blakes Bricks Ltd, Killarney Cape, 1967

FIGURE 13

Two methods of costing could have been applied. The first would assume that the product was to be fired in a kiln, and were that the case, then the costing would be based on the relative masses of the products, but adjusted with a "throughput factor". In the case set out below it was assumed that the hollow blocks could be fired in clamps and that implies that while the relative mass will govern the amount of fuel added to the unit, the volume of the unit will determine the amount of fuel added to the scannels.

A major consideration, not dealt with above, concerns the relative capital costs of cement block plants and clay block factories. While it is true that clay bricks can be handmade with the minimum capial cost of a few wooden moulds, this is not the case with a hollow block factory manufacturing 2 000 000 clay blocks per month. In this latter case the investment is in the order of millions of rands. On the other hand, a small cement block factory producing 500 000 maxis a month, on one shift, could be set up for less than R250 000. It is even possible to make a reasonably acceptable cement product with a simple mixer and "egg layer" block machines, setting the product on a concrete slab. In this latter case, a mixer, two "egg-layers" and a slab with a few wheelbarrows need cost no more than R100 000. There are also expensive, large volume, sophisticated cement plants operating in South Africa. The conclusions reached in this study suggest a possible way of using the clay plant for 24 hours per day. To a certain extent this will redress the imbalance betweem the capital costs of the competing plants.

Comparisons between tables 6, 7 and 8 clearly indicate that, if it is possible to make solid clay bricks profitably at R230 per thousand then the WB 2 at R198 can be produced to compete with cement imperials. The WB4 or Maxis at R202 are dramatically cheaper than clay maxis produced in tunnel kilns and considerably cheaper than, even discounted, cement maxis. The clay WB6 at R351 competes with the Inca price of R480. Clearly if the Maxi were to match the cost of the lowest cement maxi price quoted in March 1993 by Integrated Mangement Services at R260 this would mean that, reversing the calculation, the solid clay brick equivalent would be R296 which compares favourably with the highest clay brick quoted in March 1993 by IMS as R270.

		BRICK	JUMBO 2 WB6	MAXI/WB4	WB 2
Size of unit (mm)		222 x 106 x 73	290 x 90 x 155	222 x 90 x 115	222 x 106 x 73
Mass per unit		3.2kg	4.43kg	2.5kg	2.65kg
Units/m^2		52.5	20	35	52.5
Selling Price in Rands/thousand		**R230**	**R351**	**R202**	**R198**
Cost in Rands/m^2		R12.08	R7.02	R7.07	R10.4
Brick equiv in the wall in Rands.		R230.00	R133.71	R134.67	R198.00
PRODUCTION MATERIALS					
Clay cu m/1000		2.80	3.88	2.20	2.32
Coal kg/1000 (in scannels)		80	174.57	100.51	80
Duff kg/1000(mixed in the clay)		210	290.70	164.10	173.90
Units/m^3(clamp stacking)		582	247	429	582
Maintenance ratio based on mass		1.00	1.38	0.78	0.83
COST OF MATERIALS & MAINTENANCE					
Clay	R 2.5/m^3	7.00	9.70	5.50	5.80
Coal	R 210/ton	16.80	36.66	21.11	16.80
Duff	R 169/ton	35.49	49.13	27.73	29.39
Maintenance	R 14.5/1000	14.50	20.01	11.31	12.04
Drying cost (av. West. Cape)	R 20/1000	20.00	27.69	15.63	16.56
TOTAL IN RANDS		93.79	143.19	82.28	80.59
Selling price in Rands/1000		230.00	351.00	202.00	198.00
Profit on materials in Rands/1000		136.21	207.95	119.49	117.04

A comparison of the relative costs of hollow block comapared against solid brick

Cement products raw materials cost in Rands.	-----	125.08	246.37	141.38	-----

TABLE 9

The only reason for the thicker walled WB2 is a matter of customer prejudice. After market penetration has been achieved for the WB2 it will be possible, and desireable, to increase the size of the voids so as to match the wall thickness of the WB4, thus reducing the production cost of the WB2 even further, without prejudicing the customer.

It should be noted that Inca claim a 30% mortar saving in the use of Jumbo 2 as against conventional bricks.

4.6.3.3 Savings in clay.

Clay is a non-renewable resource and the following savings as shown in **TABLE 10** can be made by using hollow clay blocks.

	BRICK	**JUMBO 2 WB6**	**MAXI WB4**	**WB2**
Mass per unit in kg	3.2	4.43	2.5	2.65
Units per square metre	52.5	20	35	52.5
kg clay /m^2 in the wall	168	88.6	87.5	139.13
Saving in kg clay/m^2 in the wall	0.00	79.4	80.5	28.88
% saving of clay/m^2 in the wall	**0.00**	**47.26**	**47.92**	**17.19**

The saving of clay, per square metre in the wall, achieved by using hollow ware instead of solid brick.

TABLE 10

4.6.3.4 Energy savings.

Assuming that hollow blocks can be fired in clamps and that the volume of the product does have a disadvantageous effect on the energy consumption and let it be assumed that the energy required to dry a unit containing 1kg of water is 4180kJ, and yet further it is assumed that a solid brick has 500g of water to be evaporated. Then **TABLE 11** sets out the energy comparison between solid bricks and hollow blocks for firing in clamps and drying. The comparison is per square metre in the wall. Data was derived from **TABLE 9**.

	SOLID BRICK	**JUMBO2/WB6**	**MAXI/WB4**	**WB2**
FIRING				
Coal.mJ/m^2.in.the. wall	426.3	260.6	259.3	373.2
Diff vs solid brick	Nil	165.7	167.0	53.1
% saving in mJ/m^2	**Nil**	**38.9%**	**39.2%**	**12.5%**
DRYING				
H_2O/unit in g	500	692	390.6	414.1
H_2O/m^2 in the wall in kg	26.25	13.9	13.7	21.7
mJ/m^2 in the wall	109.7	58.1	57.3	90.9
Diff vs solid brick	Nil	51.6	52.4	18.8
% saving in mJ/m^2	**Nil**	**47.0%**	**47.8%**	**17.1%**
TOTAL				
Firing mJ	426.3	260.6	259.3	373.2
Drying mJ	109.7	58.1	57.3	90.9
TOTAL	536	318.7	316.6	464.1
Diff vs solid brick	Nil	217.3	219.4	71.9
% saving in mJ/m^2	**Nil**	**40.54%**	**40.93%**	**13.41%**

The energy comparison in mJ/m^2 in the wall between solid brick and hollow block.

TABLE 11.

A further consideration is the insulating properties of clay hollow-ware compared against cement block and solid brick. This is not as important in the Western Cape as in Europe, but it is a positive contributing factor to energy conservation. Pels Leusden, quoted by Handle[66] compares the energy required to produce one square metre of wall, 300mm thick, made of concrete and of brick, with the same static characteristics. He adds 5 litres of oil to the concrete figure to give the equivalent insulation.

4.6.3.5 Further considerations when drying the proposed hollow blocks which are to be fired in clamps.

It will be noted that there is a reasonable symmetry in the perforations of the proposed blocks. This will assist in obviating Wagner's[116] problem referred to in 3.4.3. above.(This was the necessity of providing equal air-flow to the inner, as well as the outer, surfaces of the block.) It should be further stressed that the residual moisture of the block, to be set in the clamp can be considerably higher than in the block supplied to a tunnel kiln. This latter factor means a shorter time in the dryer, because the block need only be dried to a level of about 5% residual moisture. This in turn means a specific energy saving.

APPENDIX 4.7 explains the production and market opportunities provided by the proposed dryer/setting machine, combined with the possibility of firing hollow-ware in clamps, for the "clamp yard" in the Western Cape.

APPENDIX 4.8 dicusses some "business ethics" aspects of the proposed production and pricing of clay hollow-ware.

CHAPTER FIVE

5.1 SUMMARY

This chapter argues the engineering system for the production of bricks/hollow blocks from the extruder, because it effects the drying process, through the setting process, in and through the dryer, so as to achieve an integrated setting dryer system which will be energy and cost effective. It does not deal with the parameters in the drying process, as such, which were established by experiment.

5.2 THE RATIONALE BEHIND THE PROPOSED DRYER DESIGN

The rationale behind the dryer design and the justifications for rejecting conventional dryers and setting machines, as used in Production Methods Two and Three, are as follows:

5.2.1 The condition of the extruded column

- The ideal situation would be that the bricks could be extruded dry, that is, without any additional mixing water being added. They could then be packed directly into the kiln, thus avoiding the drying process and the attendent handling operations. As explained above the plasticity required for the extrusion of bricks and hollow blocks cannot be achieved without the addition of water. Dry pressing has also been eliminated as a production alternative.

- Stiff Extrusion: The closest approach to extruding without the addition of water has been achieved by Stiff extrusion with the addition of steam or hot water as a plasticizer. Raising steam had legal and safety implications which could be obviated by using hot water or low pressure steam. It might well be that hot water or hot water and heated clay, particularly when the mined clay is not too wet, would give a satisfactory result. These additions, as referred to in Chapter Two, reduce the kilowatts necessary to extrude and can reduce the amount of water required to extrude a satisfactory column of clay.

- The addition of steam or hot water has not found favour in conventional brick factories for two reasons, namely that the extruded bricks were too hot for hand-setting and secondly there were considerable delays during automatic setting, as well as delays before the set stack was placed in the dryer, with conventional setting machines and dryers. Because of the delay, the bricks were close to ambient temperature by the time they came into contact with hot air in the dryer itself, thus negating some of the initial advantage of heating up the brick. Positive aspects still remained as there were still the extrusion advantages and there was less water to be removed using the hot extrusion technique.

- If during experimentation the economics of heating the brick internally as mentioned above were proven, as against heating the brick by conduction in the dryer, then it would seem reasonable to use a Fluidised Bed Combustor to generate hot air for the dryer, as well as hot water and low pressure steam for extrusion, with the advantage of being able to burn low grade coal.

- Experimentation would also determine the economic feasibility and desireability, or otherwise, of using microwaves to heat the column, between extrusion and cutting, as a method of raising the temperature of the brick before drying commenced. This would of course only have the one advantage of heating the brick, internally and evenly, very quickly so as to facilitate drying. The health hazard of using microwaves in a very basic and relatively unsophisticated industry with unskilled labour was a strong deterrent.

- The literature suggested that there were indeed advantages in hot extrusion and that there was considerable advantage in starting the drying process with a hot, evenly heated, brick or block. In the latter case the positive aspect was, not only from the time and heat transfer point of view, but also the advantage of the dramatic change in viscosity due to the water being between 50°C and 100°C rather than perhaps 30°C or less.

Now if the column was extruded hot or if any advantage was to be taken of the frictional heat generated during extrusion then the cut brick or block had to pass to the dryer, without delay.

5.2.2 The method of setting.

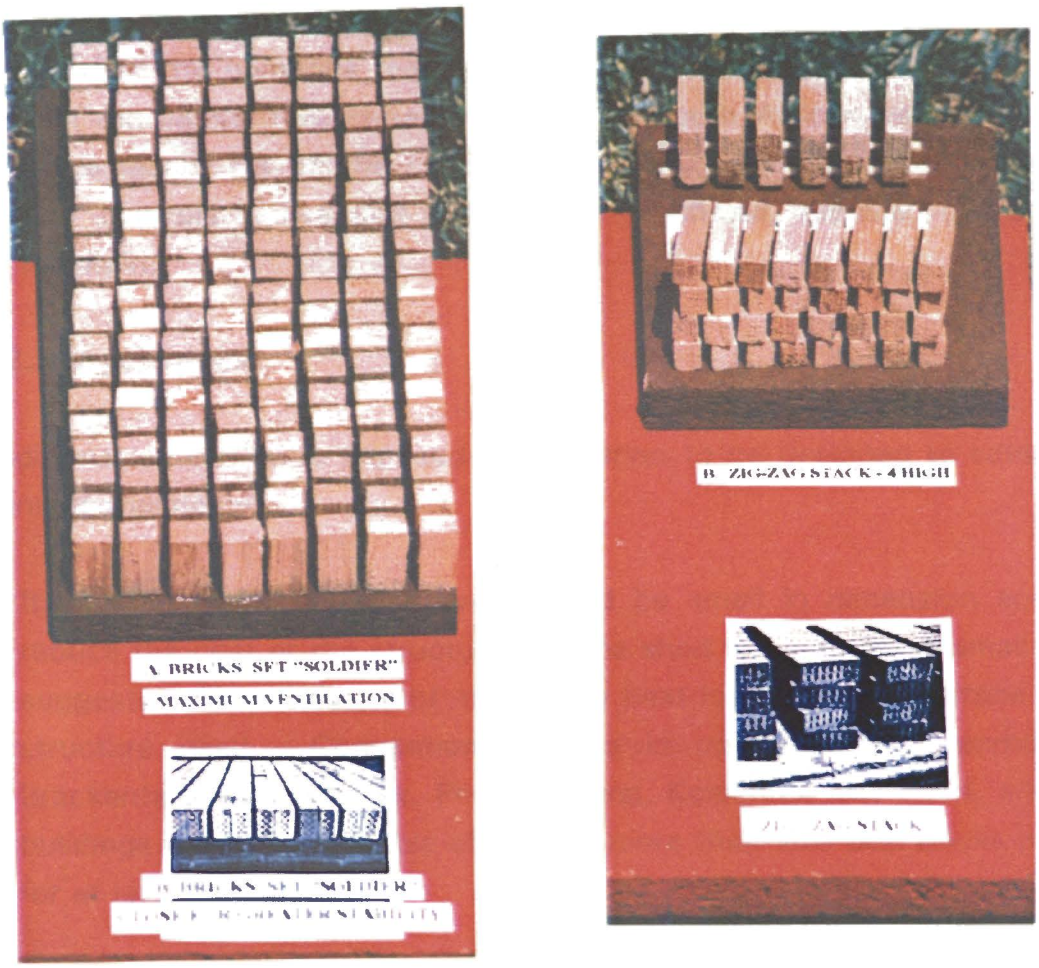
Ideally, after the bricks have been cut, they would pass, without handling, directly into the dryer. The first option was to do this with a straight conveyor belt, therefore no handling mechanism whatsoever would be needed.

- Bricks are usually extruded 222mm across x 106mm high and 75mm in length. Assuming that a 10mm space was optimum between bricks, then the conveyor drying 15 000 bricks per hour would be need to be 1275 metres long, for each hour of drying time. This was unacceptable.

- Consideration was given to the rationale behind the "ITO Technology" of Fuchs. In their plants the bricks and blocks were split apart by the simple method of differential speed belts. The Dryer/kiln car was passed under the belt at right angles to the direction of flow of the bricks or blocks. A simple arm, which was synchronised with the speed of the car, then pushed the row of blocks onto the car. In this way there were rows of blocks with a predetermined gap between them and there was a predetermined gap between each row. In the case of bricks a similar principle applied, but the bricks were set four layers high and each row of bricks was transferred onto the car with a simple mechanical clamping and lifting mechanism. The bricks were set either in a straight or zig-zag pattern. **[FIGURE 14]** In the case of the ITO plant the ware was dried in 12 hours (this time has recently been reduced) and the extrusion plant was operated on a continuous basis.

5.2.3 The satisfaction of the setting criteria

- Two criteria cited above are satisfied by the ITO principle. In the first instance transfer to the dryer can be immediate. With a little ingenuity the fact that there was a delay, while the bricks were stacked four high, could be accommodated.



The Fuchs (ITO) setting of bricks

FIGURE 14.

- Secondly their "setting machine" was extremely simple in design and inexpensive to build, so that a replacement could be kept in stock to facilitate maintenance and avoid production delays.

- Considering the simplicity of the operation it could be claimed that this was not a handling process in the conventional sense of the three Production Methods. It was hardly a machine in the normal understanding of a brick or block setting machine, if anything, it could merely be described as a setting mechanism or tool. This mechanism satisfied the demands required to improve Production Method Three, in that the capital requirement was low, a South African version could be made locally for, in the order of R 25 000, complete with pneumatics and controls. The unit was simple to install, replace, operate and maintain.

5.2.3 Dryer criteria.

Additional criteria were imposed on the dryer to be designed to satisfy the planned application.

- It was an ideal that the dryer should be small in dimension so as to reduce the cost of the structure and the shed to cover it. A small dryer suggested the possibility of minimising heat loss from the surface of the structure itself. Conventional dryers in operation at Crammix Ltd, Brackenfell and Corobrick, Phesantekraal, Koelenhof and Paarl, are large buildings which are capable of holding more than 100 000 bricks per day for at least two days.

- **A small dryer implies a fast drying time**

- If fast drying, say a time of less than three hours, were a possibility, then it would be conceivable to regard the dryer, in a sense, as an extension of the extruder. If the structure were small, it would then be reasonable to operate the dryer only when the extruder was operating.

- This last facility would have considerable advantage for the three production methods, all of which operate on a one shift basis. It would mean no overnight supervision or operation of the dryer. In a building boom, or brick shortage periods the plant could be operated on a two or three shift basis, to satisfy demand, without the need to purchase any additional plant but rather the optimization of the installed plant. This was not possible in open air drying where prepared space must be used optimally and because of travelling distance constraints. Conventional tunnel or chamber dryers are designed for a particular capacity and have drying times in the order of 48-72 hours. The proposed flexibilty provides the brickmaker with a tremendous economic advantage, particularly as certain of the above principles could be applied in a similar way to the firing process and thus free the brickmaker from the need to employ additional labour to handle "surge" production. In the case of clamp production a simple off-loading mechanism could set blocks of some 500 units, which could then be set automatically, in clamps using a fork-lift as referred to above. In Austria the I.T.O. Factory at Furstenfeld operates with two operators per shift, with an electrician on call out.

5.3 THE DRYER SYSTEM.

The design parameters and the implications of the various requirements suggested the following solution to the challenge set above.

5.3.1 Air-flow

- Fast drying, according to the literature, suggests that each brick must be dried evenly. Even drying implies that, ideally, each brick should be treated in the same way. This could be achieved if each brick stood "soldier", i.e. vertically on it's 75mm x 106mm end with a space between it and the surrounding bricks/blocks. **[FIGURE 15]** The hot air for drying would be forced either upwards or downwards through the units. Further, the units should stand on supports or lathes which will not cause uneven drying on that surface and if possible the under side of the brick should receive similar treatment to the upper side. It might well be that the air need only flow from top to bottom through the pack and the operation would rely on the "bounce back" effect referred to by Thoma and Wagner(52) to even out the drying.

- The above suggested that the airflow would be through the bricks from top to bottom or visa versa or that it might be necessary to alternate the direction of air flow. This arrangement would lend itself ideally to hollow blocks and even large hollow blocks as it could obviate problems dealt with in the literature e.g. Schockert(64) and Kother(67). It was possible to arrange the spaces between the blocks to match the size of the holes in the blocks themselves and thus avoid cracking problems through uneven drying.

- The air-flow characteristics had to be determined. The velocity of the air through the ware, the need for, pulsation or not, and if so, it's frequency. The temperature profile, as well as the planned humidity levels at various stages of the drying cycle, considering the findings in the literature, were selected and then tested on the pilot plant. (which is described in the next chapter).

5.3.2 Materials handling

The column could be cut as described above but it was decided that it be cut with a simple inexpensive Hydraulic/pneumatic Cutter built by Claytile (Pty) Ltd. at Koelenhof. This cutter cuts 30 bricks at a time. It is a side-board cutter and combines well with subsequent movements and the simple mechanism for splitting the bricks so that they have an optimum gap between them. The block of 30 separated bricks could readily be turned through 90^{o} and then be set "soldier" in the dryer.

In the case of hollow-ware, when WB2 and WB4 blocks are produced they are extruded in twos parallel to each other and can be cut to a length by an inexpensive Brazilian cutter, which is on the market. The direction of extrusion and cut lend themselves admirably to simple setting, again "soldier", so that the air can pass vertically through the perforations and past the side of the hollow blocks. These two blocks travel side by side on a belt for some two metres where they are transferred and turned in their length through 90^{o} to stand soldier on a belt running at right angles to the travel of the extruder belt. (The mechanism used to achieve this motion is extremely simple and does not damage the faces or arrises of the blocks). This latter belt is synchronised with the cutter and registers a set distance with each cut, so as to separate the sets of two blocks. (In the extrusion, the two blocks extruded simultaneously are already separated by a die spacer). Once a set of blocks, the width of the dryer, standing soldier, reaches a position exactly in front of the dryer, they are clamped with a pneumatic clamp on both sides of the row of blocks, lifted with a simple gantry and are transported and placed in the dryer, with a pre-determined distance between each row.

This cutting and setting combination applied the ITO principles and achieved the criterion of placing the bricks in the dryer without delay, should preheating of the column have been decided upon. The decision to set the blocks "soldier" was a deviation from the ITO principle in that it implied a different direction of air-flow. The decision to deviate from the I.T.O. setting is fundamental to this paper. Eustacchio[(124)] in April 1993 comments on Thoma's [(54)(55)] persistance in adhering to 40 year old technology as late as 1992. He further argues, quite correctly, that in Wagner[(116)] where it is implied that Novokeram is at the forefront of a drying breakthrough the article deals only with multi-rack dryers. It should further be added to the criticism of Wagner's paper that he still is not treating each unit as an individual, and all units in the same way, which is again a fundamental to the reasoning in this paper. Eustacchio also makes the same mistake as Wagner. He claims that traditional tunnel dryers have an air velocity in the direction of flow of 0,5 to $2ms^{-1}$ while in a fast dryer a velocity of 6 to 12 ms^{-1} is often attained. Photographs show and inspection of the plant at Furstenfeld confirm that it is not reasonable to suggest that an even velocity is conceivable in and through the block across the width of the car. The proposed dryer, with it's soldier setting, satisfies this critical criterion.

Examples of bricks standing "soldier".

FIGURE 15

5.3.3 Quantifying the dryer dimensions:

In attempt to establish the possible dimensions of the dryer, it was assumed that the above cutter cut a basic module of 30 bricks and that each brick was separated from the next by 10mm, and further, that each row of 30 bricks would be separated from the next by 10mm.

- The proposed dimensions of a module was then 2550mm x 85mm.
- Now 15 000 bricks an hour implied that the dryer would hold 500 modules or have a length of 42.5 metres per "dryer hour".
- The dryer would then be 42.5 metres long and 2.55 metres wide.

- Another alternative would be to place two modules alongside one another and this would halve the length of the dryer and double it's width.

- The mass on the dryer, due to the bricks, would be 48 000 kg per "dryer hour".

(In seeking to establish the order of magnitude of the dryer, it was realised that similar dimensions would apply to hollow block)

5.3.4 Some mechanical engineering considerations

5.3.4.1 The method of conveying the bricks.

Various methods of conveying bricks are in use. To establish which was the most appropriate the mass which had to be transported and the dimensions of the dryer had to be established. An arbitrary cut-off of a three hour drying time was decided on. This suggested itself, as beyond this some of the advantages of this concept diminished.

In choosing the method of conveyance of the bricks it was necessary, at this stage, to provide for the possibility of passing air through and under the brick supports.

- **Roller conveyors and walking beams.**

It would be difficult to transport bricks standing "soldier" on either a roller conveyor or a walking beam.

- **Cars.**

The ITO plant used kiln cum dryer cars to transport the bricks. This method had an advantage if the car was to be used for firing the bricks straight after drying but this was not a criterion for the production methods under discussion. The requirement to pass air under the layer of bricks could be met by building a metal superstructure on the top of the car but was a negative consideration when the car was to be used for firing bricks or blocks.

Cars as a method of transport in this case were rejected because they required a transfer car and a return rail system, which was wasteful of space and entailed a whole separate operation, as well as the need for additional labour.

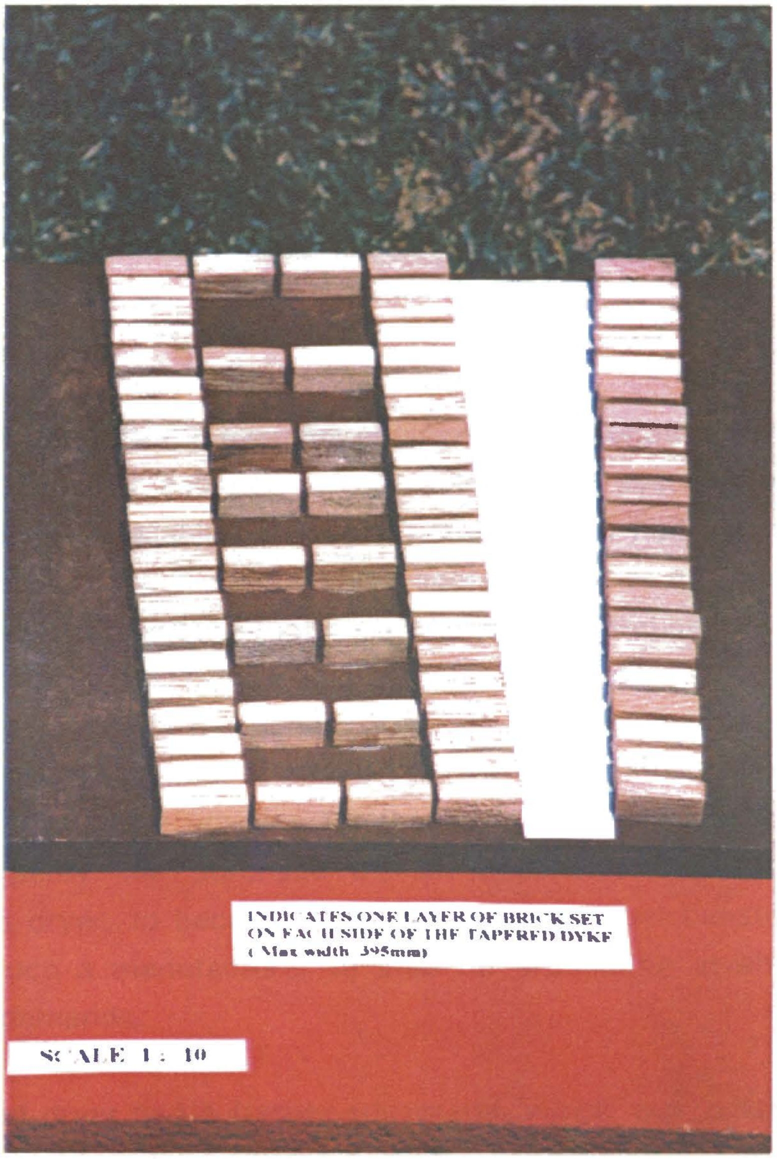
- **Mesh, slat and belt conveyors.**

The mass to be moved and the dimensions of the dryer ruled out any of these conveyors, from the mechanical engineering standpoint.

5.4 A PROPOSED SOLUTION.

One possibility, with advantages over a conventional dryer/kiln, was an annular ring. It could move continuously, or in stages, and because the ring could be supported on a number of wheels it's structure was light and inexpensive. The mass to be conveyed was not a limiting factor. There were no return cars and space was optimally used if ducting and controls were placed inside the ring, with the further facility of being able to transfer air across the ring, where necessary, from one drying zone to another. The loading and off-loading stations were placed adjacent to each other which could be turned to advantage. It must be conceded that there was a waste of space on the annular ring itself as it was proposed to set the modules in blocks each of about 1 metre long and 2.55 metres wide, to simplify setting. **[FIGURE 16].** This suggestion implied a triangle of waste space between each module but again this could be used as a seal. The problem of passing air through the base became simple because the ring could be so constructed that the metre wide module could always be stationed above an exhaust/inlet position with minimal leakage whereas in the case of a kiln car with a super-structure air had to be removed from the side of the car which posed a number of problems.

The major design problem was the need to find an inexpensive and maintenance free moving mechanism to drive the ring. The simple solution of floating the disk was rejected as being of esoteric interest.



The setting on the disk showing the "wasted" space between modules.

FIGURE 16

5.4.1 The annular disk dimensions:

The following examples give an idea of the order of magnitude of the size of the proposed dryer.

Assume that the disk is one module or 2.55 metres wide then for 1 hour drying the disk would have an I.D. $\tilde{}$ 14 metres.
for 2 hour drying the disk would have an I.D. $\tilde{}$ 28 metres
for 3 hour drying the disk would have an I.D. $\tilde{}$ 41 metres
but if two modules were placed together the width of the disk would double but the I.D. for 3 hour drying would then be $\tilde{}$ 21 metres.

5.5 CONCLUSION.

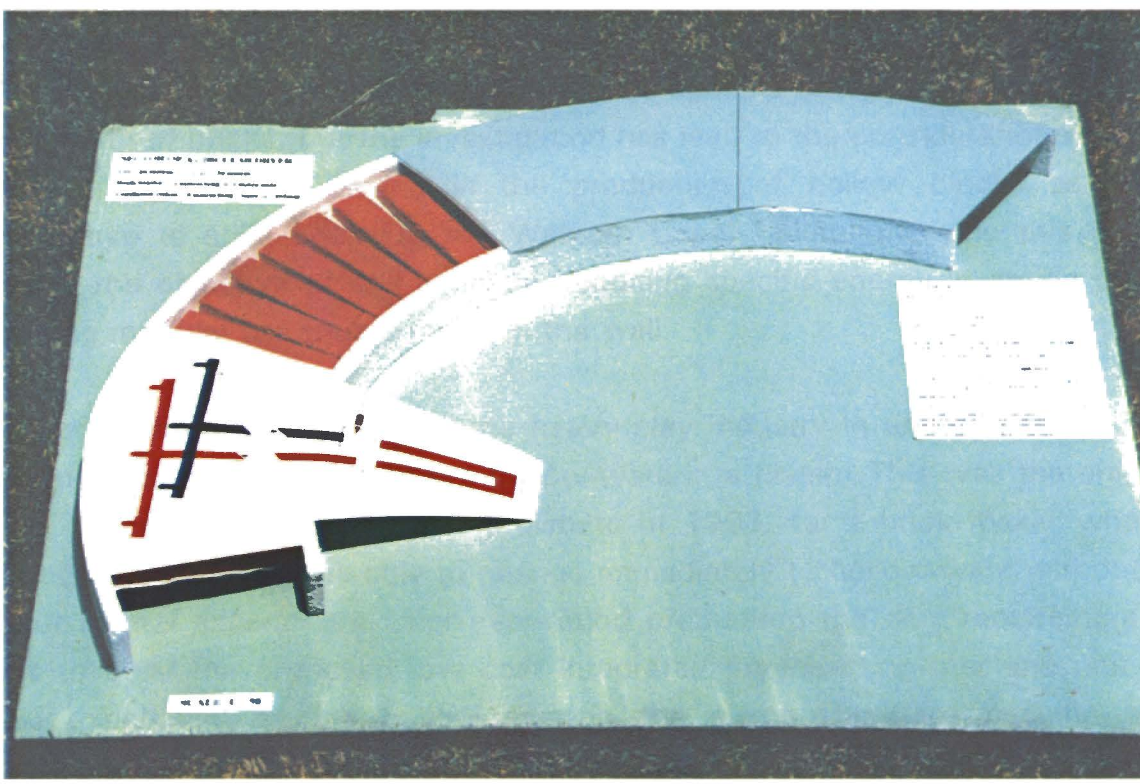
The investigation into the systems engineering produced a "dryer package" which was distinctly superior to the conventional systems of dryers and setting machines available. It was a system which had a low capital and installation cost, as well as not being sophisticated in it's operation. This system reduced the labour required in plants that hand-set and was able to obviate a setting operation by substituting a simple set of movements achieved with a simple mechanism. This set of movements could also be applied to the off-loading of the dryer. It permitted hot extrusion as a possibility and made it possible for the brick manufacturer who could not afford, or justify the purchase of, an expensive conventional setting machine and dryer, to become independent of weather constraints; further it allowed such a manufacturer to step up production at short notice to meet boom demands.

The proposed dryer had a further advantage, which was outside the scope of this paper, of facilitating clamp setting by combining it with a simple off-loading mechanism, to set square "blocks" of some 500 units, with units placed at the bottom of the block so as to facilitate fork-lift setting, straight into the clamp. (This principle is illustrated in **{APPENDIX 4.5}** referred to above.) This method would also reduce the labour requirement and reduce the waste factor, as well as making it possible for a brick maker to increase to a multiple shift operation without the need of an additional 30 or more labourers.

Further this paper merely covered only the fast drying phase of what would be an integrated fast firing and drying system, using the annular disk. This combination would obviate the cooling down of the dry bricks/hollow blocks with a consequent waste of energy as they would go directly into the kiln section of the integrated system; thus avoiding a handling operation from dryer to kiln.

It remained therefore to establish the conditions required to dry bricks/hollow-blocks, without cracks or flaws, in less than 3 hours and to operate the dryer at a level of efficiency at least comparable to the conventional dryers available.

FIGURE 17 shows a photograph of a model of the annular disk where the "waste space" between the modules can be clearly seen.



A section of the annular disk dryer.

FIGURE 17

CHAPTER SIX

- THE EXPERIMENTS -

Perhaps it is appropriate to start this chapter with a quotation from Rimpel[125], "Owing to the variety of clay deposits and types of plant with their widely differing drying properties and conditions, every drying problem has to be solved individually. There are no ready-made solutions "off the peg."

6.1 EXPERIMENT ONE - FIRING HOLLOW BLOCKS IN A CLAMP -

The subject of this paper is clearly to reduce specific energy consumption in the drying of bricks, but the investigation has lead to the consideration of an even greater energy saving in the production of hollow blocks as an alternative to solid bricks in the Western Cape. Simultaneously this will satisfy the objective of this paper by reducing specific energy in drying the building material per square metre in the wall.

To obtain the greatest gain for the heavy clay industry in energy saving, it was necessary to be able to fire hollow-ware in a clamp. This was the only way, particularly in the economic climate of 1993, for a brick maker who did not have a kiln to be able to change immediately to hollow-ware without major capital expenditure. For year-round production the only requirement was to build the proposed low cost integrated dryer/setting machine unit. This experiment to fire hollow-ware in the clamp therefore became a fundamental part of the project to reduce specific energy costs in the drying process because it has been proven that it is energy effective to dry hollow-ware compared to solid brick. (It is not being suggested that clamp firing is the most economical or from a specific energy viewpoint, the most thrifty method of firing hollow-ware or bricks.)

As has been stated above, the cognoscenti in the clay brick industry, particularly those who had produced hollow block at the two Blakes Bricks

Ltd factories in the Western Cape, namely, the Table Mountain factory at Koelenhof and the Road Afric factory at Somerset West, believed that it was not possible to fire hollow block in clamps. It was resolved to test the validity of this opinion.

The experiment was carried out as follows:

1. The green blocks were made.
WB2 and WB4 hollow blocks were produced at Claytile (Pty) Ltd in Koelenhof. Joostenberg Brick clay as well as the red and white Koelenhof clays were used separately. Random mixes of the two Koelenhof clays were also used. This was done to give a resonable cross-section of Western Cape clays which were readily available.

2. The green blocks were dried in the open air and in a dryer.

3.(a) Small pockets of blocks were packed together at various levels and positions in a clamp of a million normal solid building bricks. These blocks fired successfully, irrespective of their position in the clamp.

3.(b) A large pocket of blocks was packed in a subsequent clamp of bricks with the distinct difference that the blocks were packed in the top half of the clamp and that the pocket stretched from half way up the clamp to the top layer. These blocks fired successfully right up to the top layer, with the exception that a group of blocks made with the clay firing in the lowest temperature range were slightly distorted. This was to have been expected. **[FIGURE 18]**

This latter experiment contradicted the opinion, often expressed, that the residual moisture and the chemical moisture in the lower blocks would soften and distort the unfired blocks in the upper layers, during the firing process.

3.(c) A large pocket of blocks were packed from the bottom layer, including the coal scannels(skintels), to the top layer of the clamp. This was lit on the Monday afternoon and removed from the top of the clamp on the Friday afternoon of that week, satisfactorily fired.

The same process would have taken closer to two weeks under similar weather conditions, at this time of the year, with solid bricks. This latter factor suggested faster firing with a cost saving of "work in process".

This latter experiment clearly indicated that it was possible to fire hollow blocks in clamps and that the residual moisture and chemical moisture were not a source of concern. The experiment also eliminated the argument that it was not possible to fire ware with a large proportion of voids, as it had been argued that the essential aspect, in fact the sine qua non of clamp firing, was a dense pack. This latter argument had been refuted, in effect, by the Corobrik technique of firing the "hulo" pack as referred to above and also the fact that some factories had fired the conventional brick, with vertical holes, in clamps. It had been argued that this latter method was dependent on the substantial wall thickness of these bricks. This was also proven not to be the case.

3.(d) Subsequent tests have been carried out on semi-dried blocks mixed with dried blocks to explore the tolerances of this method and it was established that blocks are not more sensitive than bricks, to clamp firing.

3 (d).1 The tests that will follow will be to fire some 500 000 blocks, with no solid bricks, in a clamp, and then to establish to what extent the fuel, which is mixed with the clay can or cannot be reduced and to what extent, if any, the fuel in the scannels can be reduced. These latter tests do not form part of this paper.

3.(e) Tests using the present amount of fuel, both in the block and in the scannels, have been carried out successfully on clamps packed entirely with hollow block. The method is being used at present on a production scale at Claytile (Pty) Ltd.

A further advantage of firing these WB2 and WB4 blocks, in a clamp, was the fact that they were aesthetically attractive and satisfied the water absorption characteristics required for a face brick. The advantage of face brick, as against plastering or bagging, is the reduction in initial building cost, as well as a reduction in maintenance costs to the house owner. [FIGURE 19] shows the WB4 being used as face brick in an internal wall.

Hollow blocks fired in a clamp at Claytile (Pty) Ltd, Koelenhof in February 1993. The distorted blocks can be seen in the right foreground.

FIGURE 18

6.2 EXPERIMENT TWO - THE DRYING OF BLOCKS AND BRICKS IN A TEST DRYER.-

6.2.1 A Description of the apparatus.[FIGURES 20 & 21].

The test dryer was constructed out of mild steel plate and was lagged with rock wool and sisalation (Grade 240). The heat source was a set of 6 x 3kW, 220V black heat elements. The fan was by Continental Fan Works

(Model No.675 PAC, Serial No.A134/24) It was a full width radial bladed fan (max. speed 2250 r.p.m.), driven by a 7 kW motor at 1440 r.p.m. The fan description plate indicated a volume of 2,79 m^3s^{-1} and S.W.G. of 100mm.

Heat energy was provided by electrical elements, and allowed for hot air temperatures of up to 180°C.

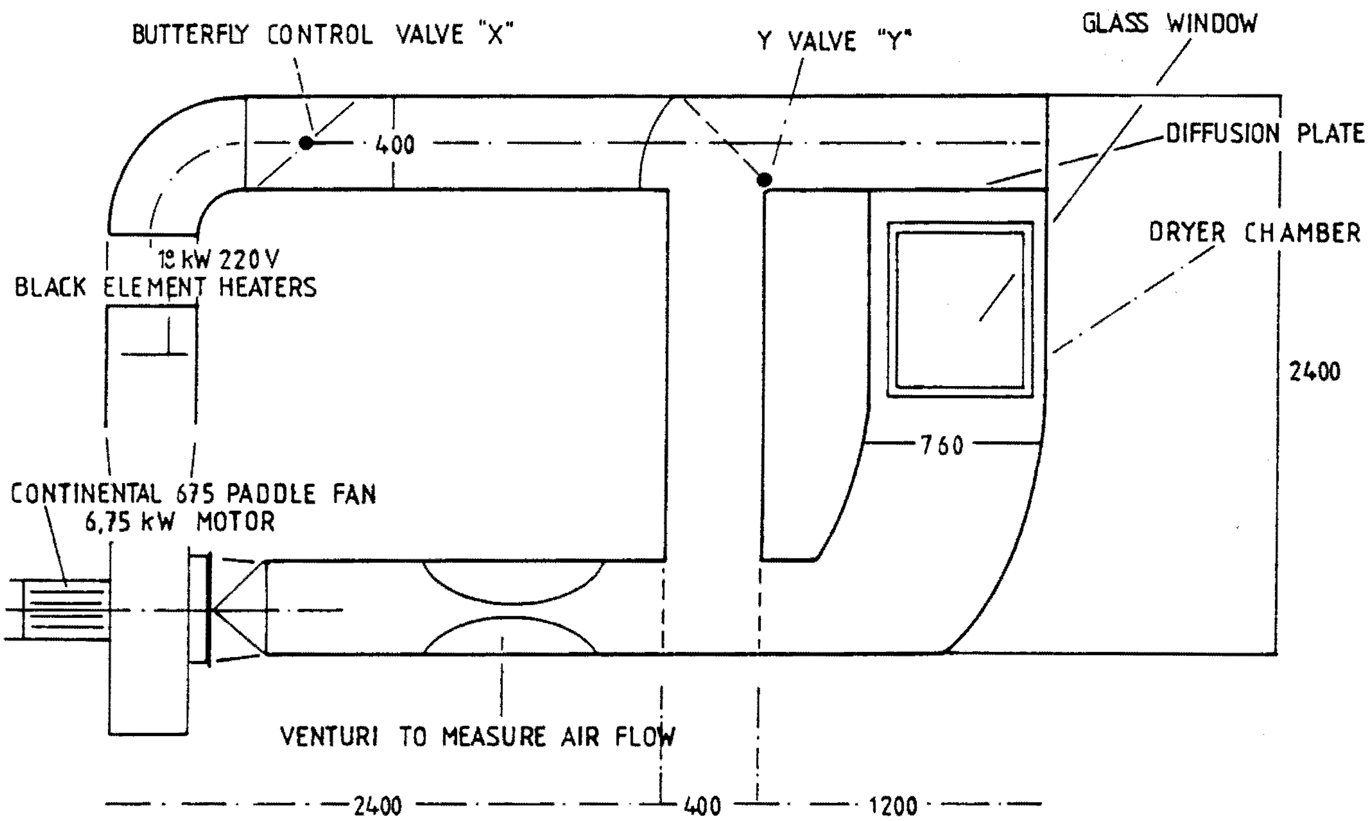
Air velocity could be varied up to 17ms^{-1} through and between the blocks. The literature indicated that air velocities in the order of 2ms^{-1} - 10ms^{-1} could be optimal.

It is possible to operate the unit as a closed system or to bleed in air as required. A open/closed mechanism, with a timer, enables the air flow to be pulsed over a wide range of pulse times.

The WB4 being used as a Face Brick in an internal wall.

FIGURE 19.

The air volume was controlled by the damper at position "x" while the damper at position "y" was controlled by a timer and a pneumatic cylinder. By operating this damper it was possible to pulse the air past the samples in the drying chamber. The temperature of the air was controlled by a thermostat 0-250°C.



An elevation sketch of the test dryer.

FIGURE 20

It was not possible to reverse the airflow past the samples in the chamber but a system was devised which made it possible to test the "bounce back" effect referred to by Thoma.[52]. A plate was placed below the support mesh on which the samples stood, to simulate the proposed car deck on the annular disk dryer. This latter aspect was only explored for completeness as it would be possible to blow air from below the setting if necessary.

6.2.2 Tests carried out on the pilot test dryer.

1. The test chamber holds:

No & Type of unit	Method of setting	Percentage voids
24 WB4 Maxis	Densely packed	30
15 WB4 Maxis	Open pack	50
24 WB2	Open pack	44,82
30 WB2	Densely packed	21,56
24 Solid bricks	Open pack	29,5

All the samples tested stood "soldier"

2. The air volume in the system was in the order of 2,3 m^3. There is a bleed-off and a bleed-in but both of these were kept closed throughout the tests. The system was not air-tight and so there was a bleed-off through holes drilled in the top of the drying chamber.

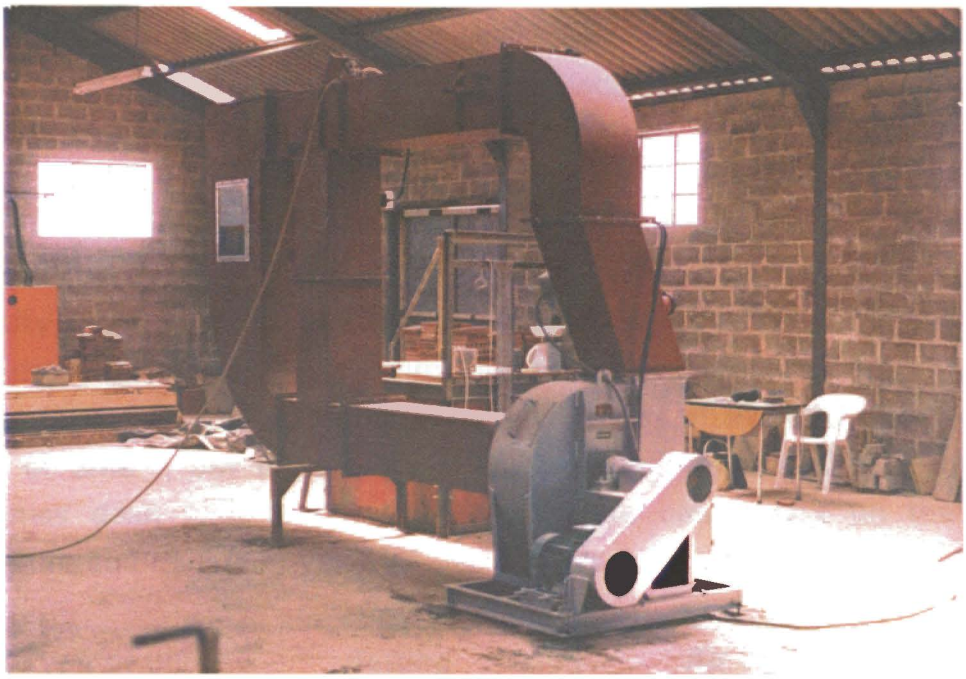
3. Two air volume settings were used on the fan, for the tests.

Volume setting	Volume in m^3s^{-1}	Pressure in mm w.g.
Maximum	2,56	104
Minimum	0,33	155

4.1 There were different starting temperatures.

4.1.1 **Method One.** The blocks were stacked and then the air and heater were turned on.

4.1.2 **Method Two.** The system was heated up and the air was re-cycled through the by-pass while the blocks were being stacked in the drying chamber.



A photograph of the test dryer

FIGURE 21

4 . The variables were as follows:

4.2 There were **two setting densities** as stated above.

4.3 **Two air volumes** were used as stated above.
4.3.1 **2,56 m^3s^{-1}**
4.3.2 **0,33 m^3s^{-1}**

5. **Two methods of measuring temperature** were used. A thermocouple was placed in the air stream after the air had passed through the block/brick

setting. The surface temperatures of the chamber and the blocks, when they were removed from the chamber, were read with an infra-red pyrometer.

6. **Pressure readings** were taken 2 metres before the fan and directly after the fan to obtain the fan pressure. The pressure drop across the blocks/bricks was measured in two positions diagonally across the drying chamber and directly above and below the blocks.

6.2.2.1. The summary of the air-flow and air pressure data.

Velocity dealt with in the literature ranging from 0,5ms^{-1} to 30ms $^{-1}$ as ideal had to be tempered with practical considerations to reduce the kilowatts in fan energy and it was resolved to attempt to operate in the order of 3ms^{-1}, but to test the effect of higher velocities. In effect the velocities dealt with in the WB4 tests were consequent on the chosen maximum and minimum volumes , as follows:

No & Type of unit	**Setting**	**Air velocity in ms^{-1}**
15 WB4	Open	17
15 WB4	Open	2,2
24 WB4	Closed	28
24 WB4	Closed	3,6

1. The air-flow data recorded can only be indicative of the order of magnitude of the actual volume of air passing between and through the blocks. A description follows as to how these figures were established using a pitot tube. It is proposed to modify the dryer chamber so that it will be possible to operate a vaned anemometer in the chamber while the door is closed.

1.1 **The High air volume setting.** The volume control damper was opened to it's maximum setting. At 100mm w.g the fan should deliver 2,7 m^{3}s^{-1}. It is very difficult to get consistent readings across the top of the chamber because a drilled mesh plate and baffle plates have been inserted to even out the flow in the chamber. An average reading for the chamber area of (750mm x 400mm) was 5,75 ms^{-1}. which implies a volume of 1,725 m^3s^{-1}

As a check a set of readings were taken across the duct (400 mm x 400 mm) between the fan and the chamber where it was reasonable to assume streamline flow. These readings averaged 16 ms^{-1} and therefore gave a volume of 2,56 m^3s^{-1}. The fan pressure reading was 104 mm w.g. and so the correlation between this reading and the fan curve reading suggested that **2,56 m^3s^{-1} be accepted for the high volume reading.**

1.2 **The Low air volume setting.** The volume control damper was set at an arbitary position which was dictated by the pressure across the fan. This position was marked for future reference. The readings across the top of the chamber were even less reliable than those for the higher velocity and it was resolved to modify the chamber so that the readings could be taken with a vaned anemometer. Eventually sets of "scan" readings were taken as a best approximation and a reading of 1,1 ms^{-1} was accepted which seemed of the right order with the fan pressure being 155 mm w.g.). **Therefore 0,33 m^3s^{-1} was accepted as the low volume reading.**

The air velocity between and/or through the blocks was calculated as follows:

1.3 THE OPEN PACK SETTING (WB4)

1.3.1. **High volume setting.** With the air volume at 2,56m^3s^{-1} and a chamber area of 0,3m^2 and 50% voids, the velocity between blocks and through the blocks is some **17ms^{-1}**.

1.3.2 **Low volume setting.** With the air volume at 0,33m^3s^{-1} then, with the same criteria as above, the velocity between blocks and through the blocks will be some **2,2ms^{-1}**.

1.4. THE CLOSED PACK SETTING (WB4).

1.4.1 High volume setting. In this case with the criteria the same as above and the voids through the blocks being 0,0912m^2 the velocity through the blocks is some **28ms^{-1}**.

1.4.2. Low volume setting. In this case with the air volume at 0,33m^3s^{-1} and voids 0,0921m^2 the velocity through the blocks is **3,6ms^{-1}**.

1.5 The Stacking or setting of the units.

Schockert(64) and Reinders, Pels Leusden, Weber(65) as well as Kother(67) indicate that it is ideal for the velocity through the blocks to equal that around the blocks. There is also a fundamental principle being followed in this paper and that is the fact that each brick is treated as any other in the dryer. It is an important fact that while an increase from 15 to 24 maxis in the test chamber, increased the capacity of the dryer by 60%, it also caused the air to pass only through the block, as against passing through and around the block. Considering the wall thickness of the blocks it seemed hardly likely that this denser setting would cause the drying time to increase by 60%. This aspect was also included in the test series.

1.6 The pressure drop across the blocks (230mm).

It was important to establish the pressure drop across the test units so that in selecting the fans for the plant dryer the lowest kilowatts per fan could be used to achieve penetration through and around the blocks.

Readings were taken at two positions in the dryer chamber each above and below the blocks and bricks.

The chamber floor was 750mm x 400mm.

Type and No of units	Setting	Temp ^{o}C	Setting and Vol in ms^{-1}	Fan Press mm w.g	Pos. A	Pos B
24 WB4	Dense	29	High 2.56	109	13,0	13,0
24 WB4	Dense	29	Low 0.33	161	2,0	2,0
15 WB4	Open	29	High 2.56	100	5,0	3,0
15 WB4	Open	49	High 2,56	-	5,7	3,0
15 WB4	Open	116	High 2,56	-	5,5	2,5
15 WB4	Open	29	Low 0,33	152	0,5	0,5
15 WB4	Open	48	Low 0,33	165	0,5	0,7
15 WB4	Open	116	Low 0,33	141,5	0,4	0,5

1.7 Temperature

In the light of the work of Smolski(113), Stubbing and Ford(122) and Bergholtz (121), it was resolved to operate the dryer above 100^{o}C, if the clays could tolerate this treatment. In keeping with Thoma's(52) reasoning, in order to achieve the most efficent specific energy consumption in the dryer, it was resolved to operate with as high an air temperature as possible, without causing physical damage to the ware.

1.8 Procedure

With the above criteria the extruded blocks/bricks were kept under plastic until they were packed into the drying chamber for testing. The blocks/bricks were removed, from the test dryer, after one hour. They were weighed and the temperature was taken at differing positions on the block with an infra-red pyrometer.

The results for the preliminary tests on WB 4s are recored in **[TABLE 12]** below.

TABLE 12.

A TABULATION OF THE RESULTS OF DRYING WB 4 BLOCKS ACCORDING TO THE PARAMETERS SET ABOVE.

ONE HOUR DRYING

WB 4 BLOCKS. Feb.1993

						TEST RESULTS				
TEST NUMBER	1	2	3	4	5	6	7	8	9	10
PACK CONFIGURATION			"OPEN" PACK SETTING					"CLOSED" PACK SETTING		
AIR SETTING	HIGH	HIGH	HIGH	HIGH	LOW	LOW	LOW	HIGH	LOW	LOW
CONTINUOUS/ PULSATING	CONT	CONT	CONT	30on/60off	CONT	CONT	CONT	CONT	CONT	CONT
VELOCITY THROUGH BLOCKS	17m/sec	17m/sec	17m/sec	17m/sec	2.2m/sec	2.2m/sec	2.2m/sec	28m/sec	3.6m/sec	3.6m/sec
BRICK TEMPERATURE	31	28	25	25	:	:	25	:	25	25
STARTING TEMP. OF THE AIR	56	100	150	144	79	116	153	110	113	145
AMBIENT TEMPERATURE	28	28	28	29	:	29	30	:	29	29
CHAMBER SURFACE HIGHEST TEMP.	106	110	:	107	111	110	:	:	88	105
CHAMBER SURFACE , LOWEST TEMP.	56	94	109	103	79	101	:	:	100	105
DUCT HIGHEST TEMPERATURE	:	:	150	147	116	132	153	112	117	145.6
DUCT LOWEST TEMPERATURE.	:	:	120.9	134	79	106.5	122	95	102	110
WEIGHT LOSS AFTER 30 MINS		394gms	407gms	279gms	:	:	:	:	:	:
WEIGHT LOSS AFTER 1 HOUR (1)	488 gms	:	491gms	439gms	400gms	450gms	457gms	504gms	406gms	314gms
SAMPLE (2)	483 gms	:	:	387gms	399gms	468gms	455gms	499gms	376gms	360gms
SAMPLE (3)	483 gms	532gms	Exploded	3766gms	395gms	467gms	413gms	490gms	399gms	360gms
WEIGHT LOSS ON STANDING	:	:	35gms	:	:	33gms	:	:	:	:
WEIGHT LOSS IN DRYER	13.69%	15.10%	14.06%	11.66%	11.08%	12.96%	12.64%	13.98%	10.99%	9.96%
TOTAL AV. WEIGHT LOSS INCLUDING COOLING CALCULATED ON A DRY BASIS	14.62%	16.12%	15.00%	12.63%	12.00%	13.82%	13.25%	14.91%	12.11%	10.92%
MAXIMUM WEIGHT LOSS IN GRAMS							575gms			508gms
MAXIMUM WEIGHT LOSS %							16.20%			14.58%
BLOCK TEMPERATURE										
UPPER END	108	112	123	96	85	102	112	96	94	104
LOWER END	94	104	111	74	48	71	80	90	52	60

NOTE: (1) An increase from 15 to 24 blocks implies an increase of 60%

(2) In Test No.3 sample No 3 lost only 35gms or 1% after a further 30 mins drying.

CHAPTER SEVEN

- RESULTS -

7.1 The results of experiments in firing hollow ware in clamps.

The results of firing hollow blocks in clamps were a product of consistent appearance and quality with no apparent firing flaws. The waste figure was similar to that experienced when firing solid bricks made of the same clay. The quality of the blocks was satisfactory and they could be used as economy or semi-face bricks.

Although not necessarily dependent on the method of firing, it was decided to test the compressive strength of random samples, taken from the blocks fired in the clamp. These compressive strength tests were carried out by the Portland Cement Institute and are set out in **APPENDIX 7.1** The average of 10,4MPa compared favourably with the SABS specification of 7MPa for solid NFP's. The compressive strength test carried out on a random WB2 sample was 25 MPa.

7.2 The test dryer requirements for WB4.

In view of the satisfactory results in the firing of hollow blocks it meant that the drying results on hollow blocks were, at this stage, more significant than solid brick. It could well be that the solid brick would no longer be used in South Africa as a common, stock or backing brick, but that it would be replaced by hollow-ware and that solid bricks would find application only as engineering bricks and face bricks. A consideration when establishing the drying time, at this stage, was the fact that it would not be necessary to dry the bricks to a level of below 5% residual moisture, for clamp firing.

7.2.1 The preheating of the brick and block.

It has been established that it would be advantageous to preheat the brick/block before it entered the dryer. The extrusion plant, on which the bricks/blocks were made, was not set up to extrude with either steam or hot water. Attempts were made to pre-heat a unit with a commercial microwave oven but this was unsuccessful, as were attempts to heat units with infra-red lamps, without actually drying the unit. It was decided that heating the unit could only have an advantageous effect on the results and it was decided to wait until the production dryer had been built before connecting hot water or steam to the extruder.

7.2.2 The drying tests.(A brief description of the results in TABLE 12).

The aim of the 10 tests was merely exploratory,to establish broad parameters.

A brief discussion of the tests 1 -10.

- A general observation is the fact that, because the residual moisture for clamp firing is not as critical as that for firing in a tunnel kiln, and even more particularly in a fast firing tunnel kiln, all of the results in tests 1 to 10 were acceptable for clamp firing..

- The next significant observation is the obvious desirability of passing air from alternate sides of the block. This is the problem referred to in the literature, namely, the need for a change of airflow direction in a chamber dryer. In the test unit the airflow is only in one direction and the effect on the block over a length of only 232mm is clearly noticeable, in the tests. The hot air only came from one direction, namely, the top. The pattern of drying proceeded from top to bottom of each block. As the hour passed the level of moisture, indicated by the water line, receded towards the bottom of the block. These observations were corroborated by the temperature readings of the block itself, immediately after it had been removed from the dryer. It was noted that in the dense settings, with low velocity, the blocks had not reached near 100°C after the hour. With high velocity the block was more evenly heated but remained below 100°C, implying a certain amount of residual moisture.

- The significance of **Test 4,** where the air-flow was pulsed, (positive for 30 seconds and stopped for 60 seconds,) is that there seems to be a potential for the reduction of power consumed, as well as a possible reduction in the number of fans which need to be used in the plant dryer. In spite of the high velocity and high temperature of 144°C, the block temperatures were relatively low .

- With the open setting, if the pulsating result is ignored, the results, as expected, favour the higher velocity **(Test 1,2 &,3)** and only in the case of **Test.1**, where the temperature starts at 56°C, do the blocks not reach 100°C, both top and bottom.

- Although Eustacchio claims to have a velocity of 6 to 12 ms^{-1} passing through the blocks in the ITO dryer, this is not so. A compromise has to be found between the ideal velocity for maximum heat transfer and the economy of fan power. The proposed soldier setting with air feed from both top and bottom implies a certainty that the air will pass through the block rather than the wishful thinking of the ITO dryer. It will be recalled that while Eustacchio claimed an air velocity of 6 to 12 ms^{-1}, subsequent discussion (May 1993) with Fuchs has revealed that the velocity referred to is that passing above the ware, and they believe that the velocity through the ware will be between an half and a third of the velocity above the ware. The air velocity of 2,2ms^{-1} in **Tests 5,6 & 7** seems to have provided a satisfactory result and in the case of **Test 7**, left a block with a residual moisture of 2,95%. With the low velocity and even with the high starting temperature of 153°C the blocks at best reach only 80°C at the bottom of the block.

7.2.2.1 A caveat

- One of the weaknesses of these tests, is not only the fact that the determinations were not done at least in triplicate, but also that the units were not dried completely, until no further moisture could be removed. In **Tests 7 and 10** where this was done, there is a difference of 1,62% moisture. This difference is disturbing as it is believed that controlled experiments with reproducible results are desirable if optimum drying conditions are to be established. Another example of the uncertainty in these results was the fact that 16,12% in **Test 2** was removed in the dryer, this was higher than the total mass loss in **Test 10**, further, that only 15% water is removed from **Test 3** which operated at the same velocity and a higher temperature than **Test 2**.

In these tests there was an assumption that one hour was a reasonable test period. One hour drying is a basic parameter but it is not necessarily the time required to achieve the ideal residual moisture as defined by Thoma above. To illustrate this point, it is noted that in **Test 3**, sample No 1 was removed after 30 minutes and weighed, showing a mass loss of 407grams and yet after a further 30 minutes, it had lost only an additional 84grams. This result and similarly **Test 2** suggest that the exact retention time in the dryer has to be established, for a particular air velocity and temperature, to achieve the ideal residual moisture desired.

7.3 THE PROTOTYPE DRYER.

Further parameters were set for the ideal dryer, these included, amongst others, the need to minimise labour by combining the dryer with a simple setting machine, have low capital and maintenance costs, and of course be energy efficient.

Ideal heat transfer and water removal conditions were established from the literature. Tests done on samples provided sufficient information to warrant the building of a production sized pilot plant.

The test dryer had proved that hollow ware could be dried to a residual moisture level of less than 5% in one hour. This level of drying was adequate for packing directly into a clamp and could be compensated for in the preheat zone of the firing operation, if fast firing was contemplated.

The dryer was designed and constructed with the following characterisics.

- heat losses from the structure have been minimised due to the dramatically reduced dryer size and structure,
- the enthalpy in the moist air has been retained by reheating the process air,
- compared to conventional dryers, the air employed in the process is a minimum,
- the exhaust air is a minimum.

In the final production dryer it will be possible to use the comparatively hot exhaust air to warm air, and hot water for extrusion.

The above operational factors suggest that this dryer will be at least,as energy efficient as any dryer commercially available at present.

As with regard to energy efficiency the literature required that the enthalpy in the moist air should not be lost and that the moist air be re-heated, this has been done. The literature required that the dryer be operated at a high temperature, for efficiency, and this has been achieved. Because at this stage, to reduce capital cost, direct firing with coal was proposed, instead of an air to air heat exchanger the additional air added is that necessary for combustion. Stubbing and Ford[(122)] suggest that the hot wet exhaust air can be passed through an air to air heat exchanger to recover hot water at 70^{o} C and preheat the fresh air. To avoid the cost of an heat exchanger, initially the exhaust will be passed through the coal bed, with hopefully the advantage of a water gas reaction, cold air will pass over the grate.

If the the prototype dryer is compared against commercial dryers available it must be recognised that the only similar concept, which has stood the test of time, is the ITO project of Fuchs. Fast dryers are being proposed by Keller and others. The quotation by Fuchs for a complete, installed integrated system at R10 000 000 certainly does not satisfy the low capital cost criterion.

The air velocity through the ware has been set at $3ms^{-1}$. As a safety precaution the axial aerofoil fans have been designed for a higher pressure than was deteremined in the tests. This and the possibilty of varying the angle of the blades, as well as varying the fan speed, provides scope for experimentation on a plant scale. At present 84kW are being used for the recycling fans and less than 15kW for the rest of the fans. This is a total of 99kW which is less than the 140kW quoted by Keller, for a lesser drying capacity.

All the objectives of this thesis have been achieved with the notable exception of not having achieved anything like the efficiencies predicted as possible by Stubbing and Ford. In fact the energy efficiency of the prototype should be established even without the heat exchanger. (R 3 000 000 funding is at present being sought to develop the Stubbing and Ford dryer to a production level.)

CHAPTER EIGHT

-DISCUSSION-

8.1 INTRODUCTION

Specific energy conservation, in the drying process, is the primary concern of this study, along with the conservation of other non-renewable resources. The study sought to find application in industry, and therefore was also concerned with capital and production costs, as well as the efficient use of plant.

It was established that the Heavy Clay Industry is a large user of energy in South Africa and that brickmaking has a record of inefficient use of energy. The European Brickmaking Industry's specific energy figures, in 1985[126], for the average of Germany, France, Italy, the Netherlands and the United Kingdom (excluding it's Fletton production) was 3080 kJ/kg of fired ware. A company, with arguably the most sophisticated plants in the country, claiming to produce about 40% of South Africa's clay bricks, has an average specific energy consumption of 4 400 kJ/kg [3]. It would be reasonable to suggest that South African figures, on the whole, might well not be as good as 4 400 kJ/kg. On the other hand many of the remaining 60% are clamp brick manufacturers who do not use energy for drying and so their specific energy consumption would be governed by the energy consumed in the clamp firing of their bricks. Huiras has reported a range of between 1700 - 3400 kJ/kg fired ware,(plus 250 kJ/kg for waste), for firing clamps in South Africa, always bearing in mind that no heat is recoverable from clamps for drying. These comparisons are of little significance when it is realised that, even in 1985, 1500 kJ/kg was considered optimum for drying and firing with new plants. In 1991 commercial plants were available from Fuchs, (1880 kJ/kg for firing and drying), and Riedel, (1350 kJ/kg for firing and drying).

If it had been the case, that it was possible to open-air dry without the use of additional energy and fire clamps more efficiently than in a kiln, then the study would have had to evaluate cost saving rather than energy saving, in the drying process. This is not the situation, as has been shown above. The challenge therefore is ultimately to achieve the results of high technology, drying and firing, with an inexpensive plant. Although this is the ultimate aim, firing is beyond the scope of this research and therefore was merely a constraint in the design of the dryer, in that, dryer and kiln, would ultimately have to be part of an integrated system.

A further concern of the Heavy Clay Industry is that clay bricks have a higher specific energy consumption per cubic metre, "in the wall" than cement bricks, which are the clay product's main competitor.

Having established the basic criteria for the research, the NFP (non-face plaster brick) section of the Heavy Clay Industry in the Western Cape was targeted for investigation.

8.2 THE NFP SECTION OF THE HEAVY CLAY INDUSTRY IN THE WESTERN CAPE

All of the NFP bricks, that is, all bricks other than face bricks, and some pavers, which are manufactured in the Western Cape, at present, are fired in clamps. This was not always the case, in fact, up to the early 1970's a large number, indeed the majority, of non-facing bricks were made in kilns.

It is not within the scope of this paper to consider the reasons why NFPs are no longer fired in kilns but rather to establish which energy efficient and economical route should be taken for the NFP section of the Heavy Clay Industry. Of particular interest was the drying sub-system.

8.2 1 Open air drying.

The perceived option of not having a dryer as a method of brickmaking is associated with the clamp kiln approach to making NFPs and perhaps indicates a mind set in the industry at present. This study demonstrates that the open-air drying option is costly in comparison to normal drying practices.

Open-air drying in the Western Cape, results in either no, or low, production in winter, as well as "unfair" labour practices. One of the largest clamp producers returns his labour to the Transkei in the winter.

Considerable losses are also experienced, other than in the winter months, and various other costs, associated with open-air drying, have been discussed and quantified.

In the Western Cape, the majority of brick makers set out to make clamp-fired NFPs and hope through selection, in the final stage, to produce a few semi-face bricks and pavers, selling at a higher price, as a bonus.

As has been stated above, the clamp is not as weather dependent as open-air drying. It is not within the scope of this paper to consider alternatives to clamp firing but rather to make it possible for a clamp yard, in the first instance, to produce throughout the year. To achieve this objective a dryer has to be built.

8.2.2 Are NFP's the ideal product for this section of the industry to produce? Is hollow ware an alternative to NFP's?

WB2 hollow blocks are exactly the same size, and can perform the same functions as NFPs. Perhaps even more suited to the low cost housing market is the WB4 or "maxi" hollow block.

These hollow blocks, and many others, were previously made by the Road Afric Factory in Somerset West and the Mountainside factory at Koelenhof (both in the Blakes Bricks Ltd group), as well as, to a lesser extent, by other factories, in the 1960's. All of these hollow blocks were fired in kilns. These lines were discontinued when Blakes was bought out by Corobrik.

The drying and firing times of NFP's can be reduced if the wall thickness of the unit is made thinner. This can be done by making holes in one of two directions through the unit. The holes are either vertical to the ground when the unit is built into the wall, which is the system favoured in Northern Europe, or parallel to the ground, which is the Southern European and South American preference.

The advantages of hollow ware, as against solids, are such that they favour the objectives of this study.

- A reduction in specific energy per comparable solid unit, both for drying and firing,
- the use of less clay,
- increased productivity for handling, both in production and in building.
- less breakages due to the extrusion die technique,
- lower cartage costs,
- improved insulation in the wall.

Hollow ware, for this study, dealt with the modification of the two products that are most commonly used for housing and which would be ideally suited to low cost housing. These two, are the NFP and the Maxi. The study favoured the lateral holes. By definition, in the building regulations, a solid is any unit with less than 25% voids. The proposed hollow ware would have between 25% and 40% voids.

It is of interest to note the trend in the European Community towards the use of hollow blocks as indicated in **[GRAPH 1]**.

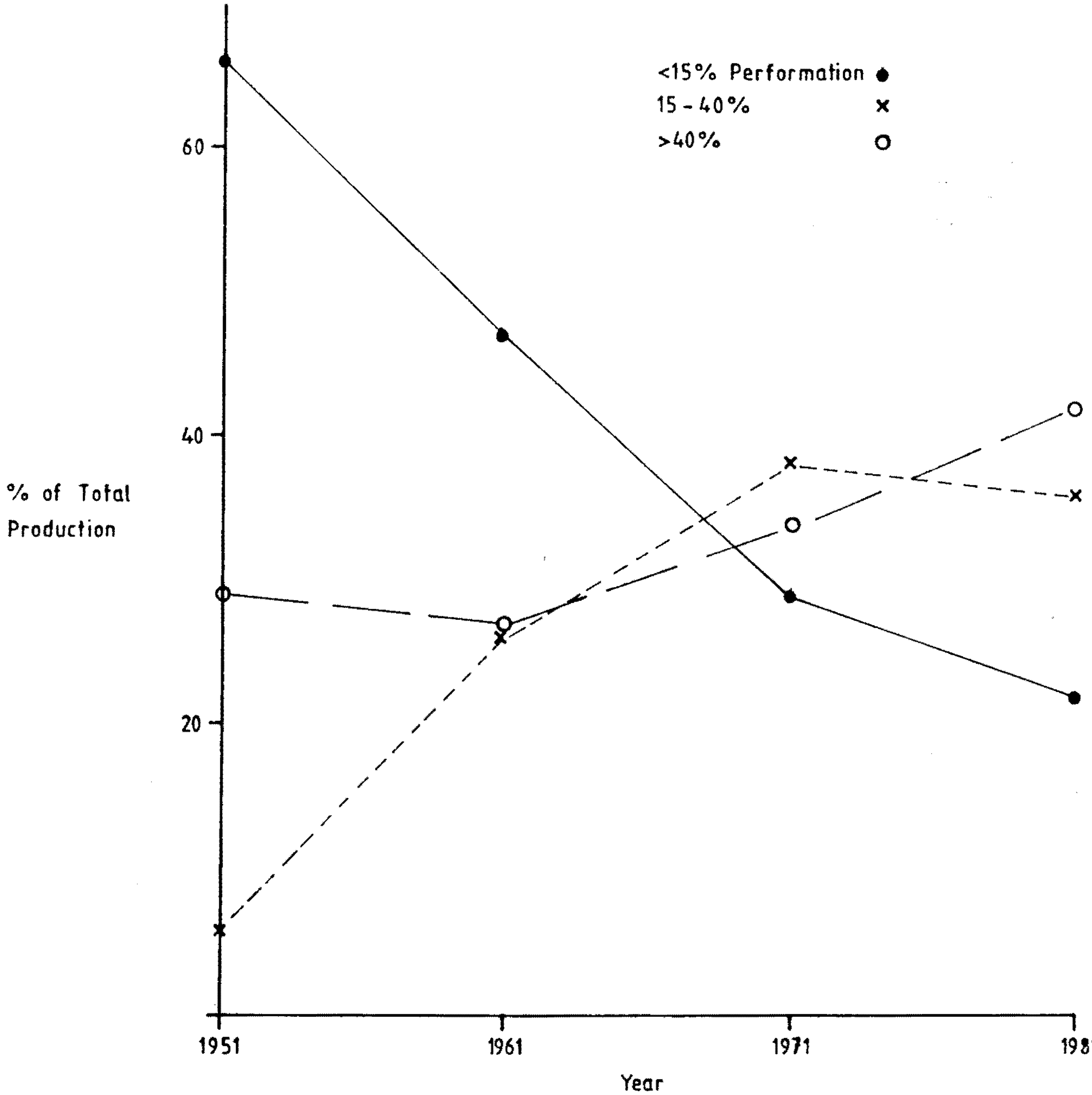
8.2.3 A consequence, for this study, of considering hollow blocks.

A basic premise for this study was the fact that clamps would be used to fire the bricks.

It was common knowledge that hollow ware is not fired in clamps and there is no record or memory of it having been done.

The firing of hollow ware in clamps was not originally within the ambit of this paper. It was realised that if this could be achieved with clays in the Western Cape, it could have a profound effect on the NFP section of the

Heavy Clay Industry and low cost housing in particular. With this latter objective in mind, and the possibility of better achieving the primary aims of this study, it was decided to test the possibility of firing hollow ware in clamps, with Western Cape clays.



ENERGY AUDIT NO.5 (1985) CLAY-BRICK INDUSTRY IN THE EUROPEAN ECONOMIC COMMUNITY

CHANGES IN PROPORTIONS OF BRICKS WITH DIFFERENT PERCENTAGE PERFORATIONS.

GRAPH 1

8.2.4 The hollow ware clamp firing experiment.

A series of preliminary tests were done at Claytile (Pty) Ltd, in Koelenhof, which established the feasibility of firing hollow blocks in clamps. WB2 and WB4 units were set in small sections within a brick clamp and these fired satisfactorily. The size of the hollow block sections was increased until complete hollow block clamps were fired.

At present one factory at Claytile has operated for 4 summer months producing WB2 and WB4 blocks. They have been stacked on pallets to open-air dry and have then been fired in clamps. The hollow blocks produced at this factory have been made with walls a little thicker than is proposed in the study. This has been done only to compensate for handling and transport, within the present production process.

The process of firing hollow ware, successfully, in clamps, has been proven. An unexpected advantage of this method has been the more rapid fire travel compared to solid bricks. Cold to cold firing times of 5 days have been established, compared to, in the order of 3 weeks, for a similar clamp packed with solid bricks. This has the economical advantage of a reduced "work in progress" time.

This "side issue" of firing hollow blocks in clamps was dealt with satisfactorily and thus permitted the continuation of the study of drying both hollow block and bricks, to satisfy the needs of NFP factories in the Western Cape.

8.3 THE DRYER

It was decided to set a number of criteria for the proposed dryer, as an alternative to open-air drying.

- The dryer should be energy efficient,
- have low capital and maintenance costs,
- be of simple construction and be simple to operate,
- have a low labour requirement,

• have production flexibility.

The first four of the above criteria would be measured relative to commercial dryers at present available. The criterion of low capital cost would be in the order of probable savings over a year or two at the most. This completely arbitrary target should be acceptable to any manufacturer.

8.3 1 The literature survey required to design the dryer.

The literature survey was divided into two sections, the first dealt with the basic principles and problems of drying heavy clay products and the second considered innovations and the engineering problems in the field of drying.

8.3.1 1 The basic problem and principles of drying clay units

It has been confirmed by experiment that it is possible to dry a single brick in a very short time, without any drying faults, with Western Cape clays.

Commercially available dryers usually dry bricks in stacks or individual bricks are set in rows, on lathes, in chambers. In either case each brick is treated differently from another, with the result that, some bricks dry before others. Those that are already dry have to wait for the slowest in the chamber to dry before the batch can be removed.

Considerable research has been done on the effect of the position of bricks and blocks relative to one another, their position on the lathes, the velocity of the air and whether or not the airflow should be intermittent or not, and if so, why?. The former points are irrelevant if each unit can be set so that it is unaffected by it's neighbours.

In the light of the literature and initial experiments it was decided that the most efficient method of drying, which would also need the smallest dryer, would be a dryer which treated each unit in exactly the same way. Units would be removed from the dryer as soon as they were dry. This meant that each brick would be subject to treatment closely resembling the laboratory situation, and if that could be achieved, drying times similar to laboratory tests, could be achieved on a plant scale.

A very important point which was derived from the literature was the ideal of having the air velocity constant and equally humid on all surfaces of the unit, particularly in the case of hollow ware.

The literature provided temperature and air velocity guidelines as well as other criteria to achieve optimum drying.

8.3.1.2 The physical design of the dryer.

The state of the industry, as well as dryers of the past, were considered along with "innovations" and the latest developments.

Consideration was given to handling procedures with the view to constructing simple inexpensive handling equipment to reduce the labour required to operate the plant. Dryer size and conveyance methods were also investigated.

It was appreciated that while the situation in the Western Cape, at the present time, required that clamp firing should be accommodated, this would not necessarily be the method of firing in the future. It was therefore assumed that the dryer should, ideally, be designed as part of, what would eventually be, an integrated drying and firing unit.

The unit most closely suited to the above criteria was the ITO system of FUCHS. It did not satisfy the basic requirement of treating each unit individually and in fact the claims made on behalf of the system with regard to air velocity and uniformity of flow were found to be unacceptable. An alternative solution and basic modification to the ITO system was to set the units soldier on an elevated grid. This allowed the units to be set in such a way that the air flow could be even around the unit. It was also possible to pass air from both above and below the setting.

The second major deviation from the ITO system concerned the conveying of the set units. ITO uses cars which are both dryer and kiln cars. In an attempt to avoid the problems of transfer cars, at the ends of both the dryer and kiln, an annular disk was proposed as the conveying mechanism. The annular disk has advantages over cars in that the disk is a continuous ring which avoids the problem of leakage between cars, leakage is a problem with conventional kiln cars.

8.3.2 The dryer experiment

The experiment, was originally planned to test the possibility of drying solid bricks in less than three hours and to be able to dry the bricks so that they could be set with a simple setting mechanism. As stated above, the importance of hollow ware as a method of reducing the energy consumed in producing building material in the wall, became very significant after the investigation had begun, and opened up further immediate possibilities. The solid brick faded in significance for conventional building, as the possibilities of hollow block developments became a reality. The emphasis of the experiment changed and it was decided to investigate the fast drying of hollow-ware, and, for completeness, the fast drying possibilities of solid bricks.

A test unit was built merely to have a controlled experiment which could simulate possible plant conditions. A series of exploratory tests were carried out, which fulfilled expectations.

It was therefore decided that:

- on the basis of the work done and the fact that the main parameters had been established,
- in spite of the incompleteness and inadequacies of the test results,
- it was an economically justifiable risk, to build a prototype dryer, which could handle the production of a relatively small extruder.

It was further decided to build the prototype dryer as a straight line conveyor and not on the annular disk principle. This decision allowed flexibility in length and the possibility of adjustment in width at minimal additional cost.

Flexibility was also catered for in that it is possible to adjust both the speed and the blade angle of the axial aerofoil fans.

A simple coal firebox was to be built as a heat source for the initial production runs.

Structural adjustments to change air flow and to facilitate heat recovery needed to be simple to make.

Finally, it was concluded that the prototype dryer, built on an industrial scale, would facilitate the building and testing of the setting machine. The fact that the dryer was straight line and not an annular dryer would in no way effect the design of the setting machine.

8.3.3 The prototype industrial dryer.

The production criteria for the dryer were as follows. The dryer was built to carry 106 000 WB4 in open setting and 145 000 densely stacked WB4, or alternatively 125 000 WB2 or solid bricks in open setting, in 24 hours. The retention time in the dryer would be 1 hour.

The dimensions of the dryer conveyor support are 29,5 metres effective length and 2,5 metres wide. The dryer length is divided into six, equal length, modules. A plenum chamber is built both above and below each module. Each module has recycling aerofoil fans of capacity 9,25ms^{-1} and 35mm w.g. pressure, on each side. These fans suck air from the plenum either above or below the setting and return it to the matching plenum either below or above the setting. The direction of flow through the setting alternates from module to module. A baffle is placed in between modules in the lower plenums but no baffle separates the upper plenums. The fans on each side of the plenums either suck or blow against one another thus creating maximum turbulence. Belt driven fans rather than bifurcated fans have been installed in the prototype so as to allow adjustment to the speed of the fan, the angles of the blades can also be changed, as can the direction of the fans. These latter criteria provide a degree of flexibility at this stage.

The dryer operates on the "airless drying" or "steam drying" principle. Air is taken from the upper plenum of module two, but, because there are no baffles in between the upper modules, suction is created along the whole length of the dryer. This moist air is mixed with hot air coming from the coal firebox and the mixture ($13m^3s^{-1}$) at 300^oC is fed back down the centre of the dryer. This same hot air is fed, proportionately, through the floor into each module, thus making it possible to control the temperature in each module, as necessary.

Ideally the moist air would be re-heated through an heat exchanger. The products of combustion would be passed through an exhaust pipe down the length of the dryer, to recover maximum energy or be used to assist in heating the water for extrusion. If an heat exchanger is used additional air will be bled into the system. In the present prototype, direct coal firing is employed and the combustion air compensates for the "bleed in".

The exhaust is extracted from module one, which is at the entrance of the dryer. This is done to take care of gas expansion due to the production of steam and the additional air that is added to the system, in the form of combustion air, for burning the coal. Heat for combustion air and hot water for extrusion, can be removed from this exhaust.

If the dried units are not going directly into a kiln they could be cooled and the heat recovered used, to assist combustion.

This industrial prototype has operated for 6 months at Claytile(Pty) Ltd. on a production basis and lends itself, as predicted, for final tuning to achieve the stated objectives for an energy efficient fast dryer.

8.4 CONCLUSION

Having examined the more general aspects of the industry and the NFP section, in the Western Cape in particular, a wider goal has been set, not only for the brick manufacturing process but also the possibility of producing a product with advantages for low cost housing. The success of firing hollow ware in clamps has made it possible to continue production without additional capital costs for firing, at this stage. The introduction of hollow ware into the market on a large scale will, compared with solid bricks, bring about a saving in the use of clay as well as energy. It also implies a cheaper building unit, per square metre, in the wall. A low capital cost dryer has been built which is small and has the characteristics of being easily and inexpensively loaded and unloaded with the minimum of labour. It is a dryer which permits the flexibilty of either 24 hour or one shift operation, and because of it's design, permits fine tuning, to achieve optimum energy consumption.

CHAPTER NINE

- CONCLUSION -

9.1 THE CONCLUSION

9.1.1 The dryer

The initial purpose of the research project was to reduce the specific energy used in brickmaking. In the NFP industry in the Western Cape some bricks are dried in the open air, and others are dried in chamber and tunnel dryers, but all are fired in clamps, from which no energy is recovered.

The basic aim was to dry bricks more energy efficiently than in conventional dryers. The rationale behind the conceptual dryer has been proven to be correct and has achieved this goal. In fact there is a prototype dryer that fulfils all it's initial aims and presents a sound project for fine tuning. This dryer can reasonably match the energy consumption figures of FUCHS, because of the similarity in design. It also lends itself to the implimentation of the ideas of Smolski, and the "airless drying" idea of Ford and Stubbing.

It is therefore reasonable to conclude that the dryer, not only satifies the criteria of energy conservation but also permits the better use of plant, and reduces the labour normally required, to operate a dryer, without the use of an expensive setting machine.

It is fact, that in many cases, (open-air drying) no additional energy is used for drying. Therefore any dryer, no matter how efficient, is going to increase the energy used, and the cost, in the plant.

The brickmaker is concerned with profitablility. The capital cost of two, 4 tonne, Bell forklifts, has been set as the upper capital cost limit of the dryer. The labour requirement has been reduced. Waste and weather dependence have been removed as problems. The challenge is to compensate for the energy running costs. The conclusion reached was that the addition of the prototype dryer is economically very attractive.

9.1.2 The expansion of the study to include hollow ware.

Hollow block is a proven product. After experiments in the clamp firing of hollow block had proved successful, it was concluded that they could be fired, in this way, on a production basis. This factor was of considerable significance for the NFP factories of the Western Cape.

Hollow block not only reduced the amount of clay required by 40% but also speeded up drying and firing. The most significant contributions were a reduction of some 40% (less in the case of clamps), in energy consumption, and the ability to compete in the market, against cement products, at selling prices, below the raw material costs of cement products.

In the South African context, possibly the most worthwhile conclusion reached, in this study, was the realisation that a cheaper product, in the wall, with aesthetic appeal could be available for low-cost housing. Productivity on building sites could increase. Most significant of all was the fact that if the dryer was built, all plants could immediately go on to 24 hour production. This alone might well satisfy predicted increased demand, without additional capital costs, and plant construction delays.

9.2 FURTHER INVESTIGATION.

Further investigation related directly to this project should include the following:

- the energy efficiency of the prototype dryer,
- the effect of using hot water or steam for extrusion, on the overall efficiency and particularly it's effect on drying.
- the feasibility of stacking hollow ware, mechanically, in clamps.

Clamps are well established in South Africa, in spite of the disapproval of the air pollution authorities. A detailed study of clamps, with possible modifications, could prove rewarding.

The prototype dryer was not designed to stand alone, but rather to be part of an integrated dryer/kiln system. Work must be done to complete this project by designing a compatible kiln.

It is important to do a study of the South African Heavy Clay Industry, in detail. It might well indicate that the proposed integrated dryer/kiln is an ideal solution, not only for the Western Cape, but also for the whole of South Africa. In the light of the availability of cheap coal, investigation could well be done into the coal firing of the integrated dryer/kiln, with small gasification units.

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APPENDIX ONE

Appendix 1.1

Product	Clay	Output (ton/ yr x 10³)	Therms per ton: Inherent and Added a	Kiln and Dryer b	Total a+b	Power* c	Other**	Net Total b+c+d	Gross Total a+b +c+d
Continuous Kilns Flettons (Facings and Commons)	Oxford	4 826.1	25.2	6.7	31.9	2.7	0.3	9.7	34.9
Common	Carboniferous	538.0	18.8+	9.1	27.9	4.2	0.2	13.6	32.4+
	Other	158.7	5.2	24.7	29.9	4.6	0.4	29.7	34.9
	Total	696.7	15.7	12.7	28.3	4.3	0.3	17.3	32.9+
Facing and Engineering	Carboniferous	927.7	5.4	32.1	37.5	6.5	0.4	38.9	44.4
	Keuper	438.5	0.1	29.2	29.2	7.3	0.4	36.8	36.9
	Etruria	269.8	0.0	28.4	28.4	6.9	0.2	35.5	35.5
	Boulder	182.6	9.9	22.0	31.9	4.3	0.5	26.7	36.6
	Weald	246.3	0.0	34.4	34.4	5.5	0.6	40.5	40.5
	Other	264.3	2.3	30.3	32.6	5.4	0.4	36.0	38.3
Stock	Various	201.4	15.0	31.8	46.9	6.1	0.6	38.6	53.6
	Total	2530.6	4.1	30.5	34.6	6.3	0.4	37.1	41.3
Intermittent Kilns									
Facing	Various	91.0	3.5	50.4	54.0	7.4	0.3	58.1	61.7
Stock	Various	77.3	20.3	31.7	52.0	3.6	0.7	36.1	56.3
Blue	Etruria	68.3	0.0	70.8	70.8	10.9	0.5	82.2	82.2
	Total	236.5	8.0	50.2	58.2	7.2	0.5	57.9	65.9

* Energy for electricity generation

** Mainly internal transport and clay winning

A SUMMARY OF ENERGY CONSUMPTION.

WALLEY C.N. & WEST H.W.H. Fuel Usage In The Manufacture Of Building Bricks(2) British Ceram.R.A.,Tech. Note 279,1978. (8). Quoted by H.W.H. West.[14]

Appendix 1.2

Electrical energy	kWh/t fired wares	
Pit operations	4 - 8 ①②	
Preparation	2 -12.5	
Shaping	5 -12.5 ③	
Dryer	6.5 -13.5	
Green brick conveyance and setting machine	0.5 - 1.5	
Kiln	6 -10	
Kiln car conveyance	0 - 0.75 ④	
Unloading and packaging	0 - 1.25	
Loading	0 - 1.75 ①	
Auxiliary equipment	0.25- 0.5 ⑤	
Total	25.25–62.25 ⑥	
Thermal energy	kcal/kg (fired wares)	kJ/kg (fired wares)
Collective average for drying and firing	350- 850	1470-3570 ⑦
Approximate values for the production of:		
Common bricks	400- 500	1680–2100
Roofing tile	550- 650	2310–2730
Lightweight bricks	350- 400	1470–1680
Split tile	600- 650	2520–2730
Engineering bricks	570- 630	2390–2650
Expanded clay	650- 850	2730–3570
Specific fuel consumption of various firing systems: ⑧		
Clamp furnace	850–1000	3570–4200
Single-chamber kiln	750–1250	3150–5250
ditto in compound (multichamber kiln)	650–1050	2730–4410
Annular kiln	320- 520	1340–2180
Zig-zag kiln	300- 500	1260–2100
Tunnel kiln	310- 600	1300–2520
Shuttle kiln	600- 800	2520–3360
Specific heat requirement for drying:	kcal/kg (evaporated water)	kJ/kg (evaporated water)
Average dryer	800–1800	3360–7560 ⑨
Chamber dryer	950–1100	3990–4620
Tunnel dryer	800–1000	3360–4200
Flash dryer	950–1300	3990–5460 ⑩

Remarks

① Most equipment is diesel-powered; the average diesel consumption is rated at 0.185 l per kW/h

② Consumption depends on the hardness of the raw materials and the thickness of the capping

③ The upper and lower values correspond approx. to stiff and soft extrusion, respectively

④ Zero consumption is for purely manual operations

⑤ Workshops, lighting, etc.

⑥ The total energy consumption usually amounts to 30–50 kWh/t fired wares

⑦ The consumption depends upon the firing and drying system, its efficiency, mode of operation, type of product, raw material properties, firing temperature and heat cycle

⑧ Gross heat input = total amount of thermal energy fed into the kiln. Appropriate linkage between the kiln and the dryer can save 20–35% of that sum

⑨ Depends on the drying system and plant efficiency; under extremely adverse conditions, the calorific consumption may attain a level of 3000 kcal/kg water

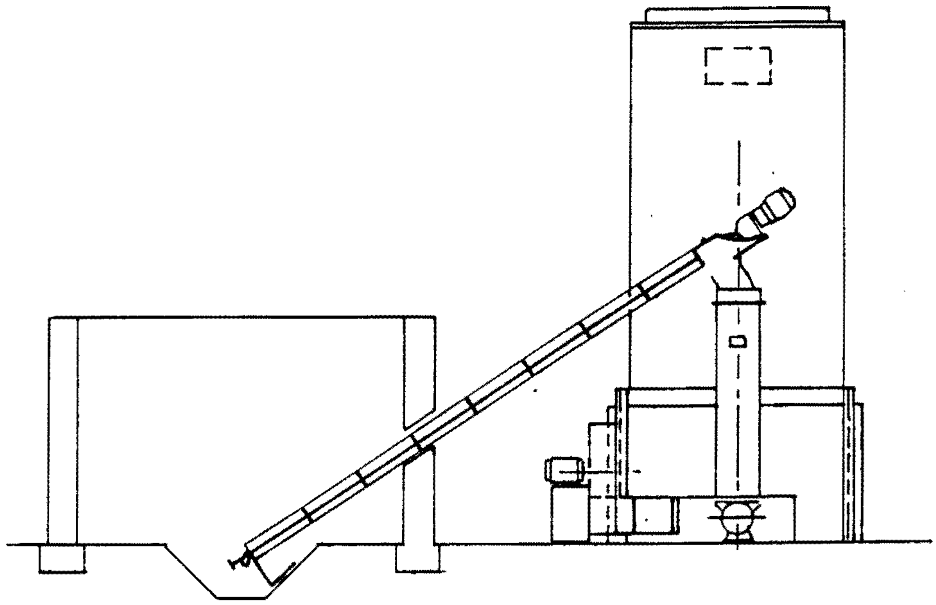
⑩ Including the thermal energy normally expended for hot shaping

APPROXIMATE ENERGY REQUIREMENTS FOR BRICKMAKING.

Schmalzried and Bender(15)

APPENDIX TWO

Appendix 2.1



REACTOR FOR THE GASOGEN PROCESS - H. Gatzke(71)

Appendix 2.2

Measures for Heat Recovery from Dryers - C Wagner(78)

Table 1 Feeding of waste heat from the tunnel kiln to the dryer.

Method	**1**	**2**	**3**	**4**
Waste heat from tunnel kiln in m^3/h	15000	25000	40000	0
% of hot air required	30	50	80	0
Temperature of waste heat ^oC	80	80	120	-
γ waste heat from tunnel kiln	1,0	1,0	0,9	-
Dry air proportion of waste heat	15000	25000	36000	-
Fresh air to be preheated via heat exchanger m^3/h	26750	16750	5750	41750

These methods are applied under otherwise equal conditions as there are:

Temperature of fresh air before heat exchanger	10^oC
Temperature of used air before the heat exchanger	50^oC
Temperature difference	40 K
Temperature efficiency of heat exchanger	0,60
Warming up of fresh air with heat exchanger	24^oC
Energy costs	0.0235 DM/MJ

Appendix 2.2 contd.

Table 2. Profitability calculation of a heat exchanger

Method	1	2	3	4
Waste heat from tunnel kiln(m^3/h)	15 000	25 000	40 000	0
Fresh air to be preheated via heat exchanger.(m^3/h)	26 750	16 750	5750	41 750
Saved heating performance when preheating by 24 K (MJ/h)	642	402	138	1 002
Saved heating costs (DM/h)	15,09	9,45	3,24	23,55
Annual working hours (h)	3744*	3744*	1248**	6240**
Saved heating costs per year (DM)	56497	35380	4043	146952
Additional costs for electricity/year (DM)	4 493	4 493	1 497	7 488
Theoretically possible annual savings of heating costs (DM).	52004	30887	2546	139464

* 24 h/day x 3days/week x 52 weeks/year = 3774 hour.
** the heat exchanger is only operated 1day/week.
*** the heat exchanger is operated 5 days/week.

Required quantity of hot air	50 000 m^3/h
Temperature of hot air	150°C.
γ hot air	0.835 kg/m^3.
Amount of dry air in hot air	41 750 kg/h

The values for different methods are given in Table 1,

Appendix 2.3

Rational exhaust utilization in the chamber dryer.H.- Thater (79)

Specific examples:

Case 1:

If air at 10^{o}C and with 90% relative humidity is heated to 50^{o}C without Introducing supplementary air, i.e. an enthalpy increase occurs, this hot air at 50^{o}C now has a relative humidity of 8%. The original heat content of the air is thus increased from 6,5 kcal/kg by 9,73 kcal/kg (corresponding to 57,4%) to 16,23 kcal/kg. Physically this is in fact correct, but, owing to the high air humidity in the first instance of 90%, the heat expended is not economic.

Case 2:

If air at 50^{o}C and with 40% relative humidity is heated to 80^{o}C, then the relative humidity is reduced to 6%, i.e. 20% new heat is introduced or, in other words, this heat engineering process operates with 80% efficiency.

Case 3:

If moist air at 70^{o}C and with 40% relative humidity is heated to 106^{o}C, the relative humidity falls to 10%, i.e. 13% new heat is produced or, in other words, this heat engineering process operates with an efficiency of 87%.

Case 4:

Moist air at 90^{o}C and with 30% relative humidity which is heated to 145^{o}C and to 5% relative humidity, increases its heat content by 13,5%. This heat engineering process operates with an efficiency of 86,5%.

Appendix 2.3 contd.

Case 5:

If moist air at 100°C with a relative humidity of 20% is heated to 143°C and 5% relative humidity, the heat content increases by 11%. This heat engineering process operates with an efficiency of 89%.

	Initial state air		Heated air			
	°C	% rel. humidity	°C	% rel. humidity	Heat feed %	Efficiency
Case 1	10	90	50	8	57,4	uneconomic
Case 2	50	40	80	6	20,0	80
Case 3	70	40	106	10	13,0	87
Case 4	90	30	145	5	13,5	86,5
Case 5	100	20	143	5	11,0	89

Appendix 2.4

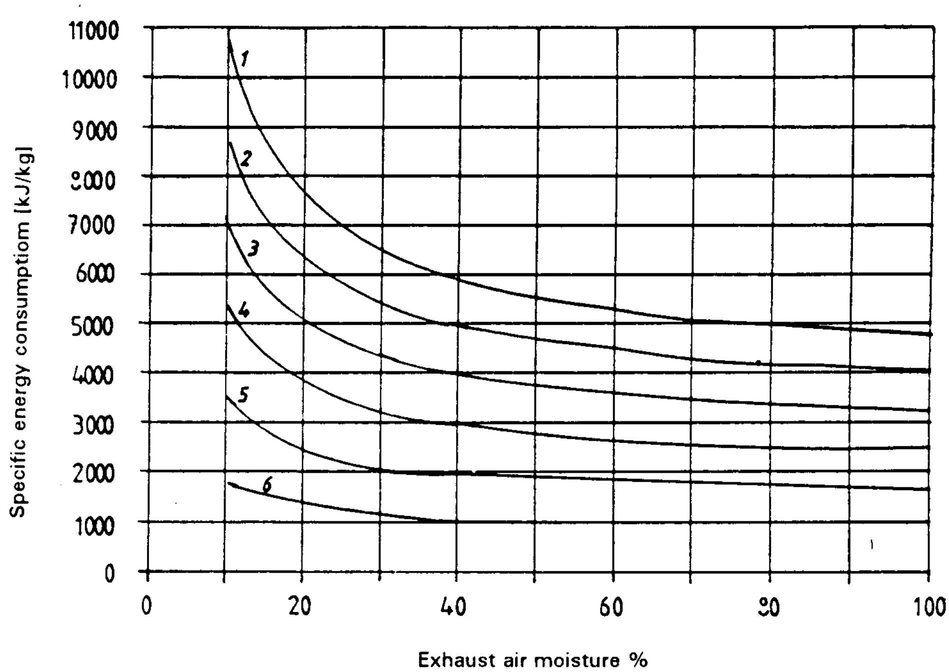
Heat recovery from the dryer exhaust

An appropriate means of reducing energy consumption? E Rimpel[81]

Appendix 2.4(a)

Relationship between spec. energy consumption and exhaust moisture and ambient air temperature.

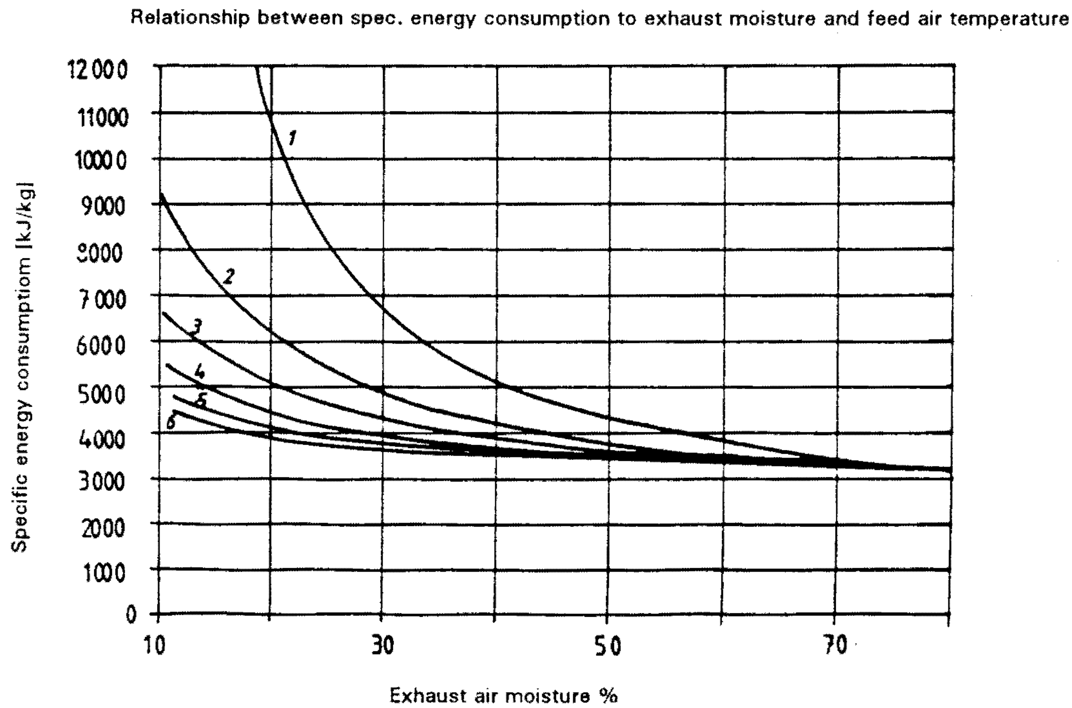
Relationship between spec.energy consumption and exhaust air moisture and ambient air



1	Ambient temp.	-20°C	2	Ambient temp.	0°C	3	Ambient temp.	20°C
4	Ambient temp.	40°C	5	Ambient temp.	60°C	6	Ambient temp.	80°C

Appendix 2.4(b)

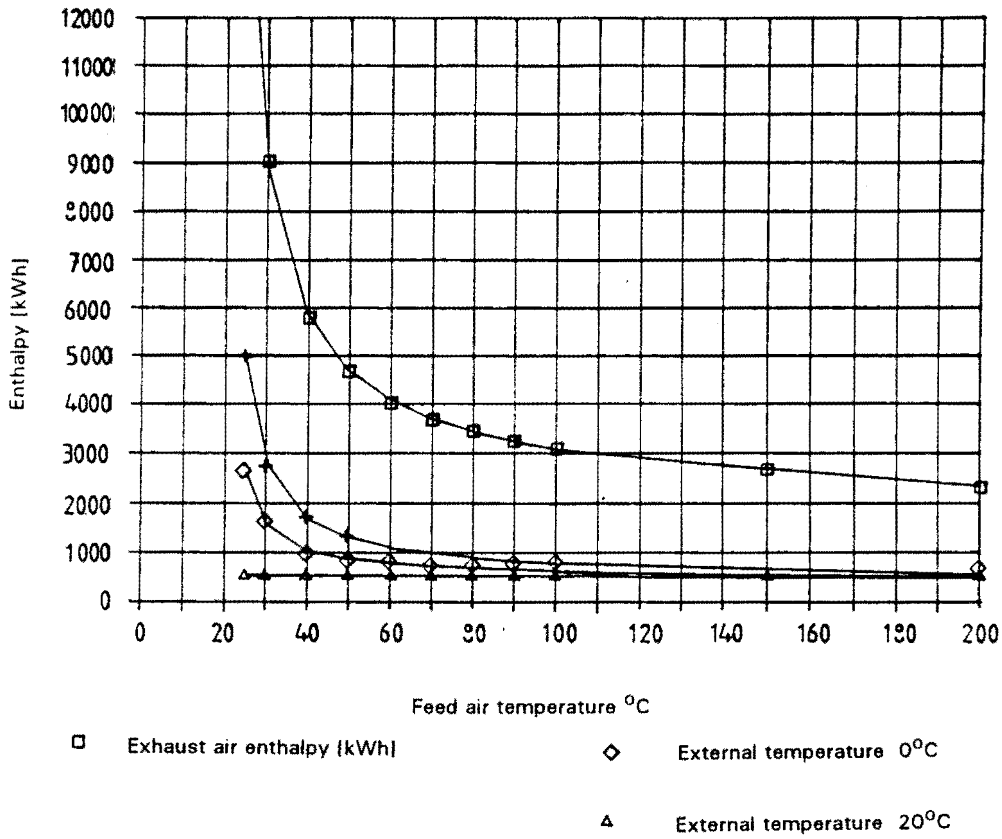
Relationship between spec. energy consumption and exhaust air moisture and exhaust air moisture and feed air temperature.



1	Feed air temp	55°C	2	Feed air temp	80°C	3	Feed air temp	105°C
4	Feed air temp	130°C	5	Feed air temp	155°C	6	Feed air temp	180°C

Appendix 2.4(c).

Amount of exhaust air enthalpy which can be utilized by exhaust air recuperation as a function of the temperature of the feed air and of the ambient air.

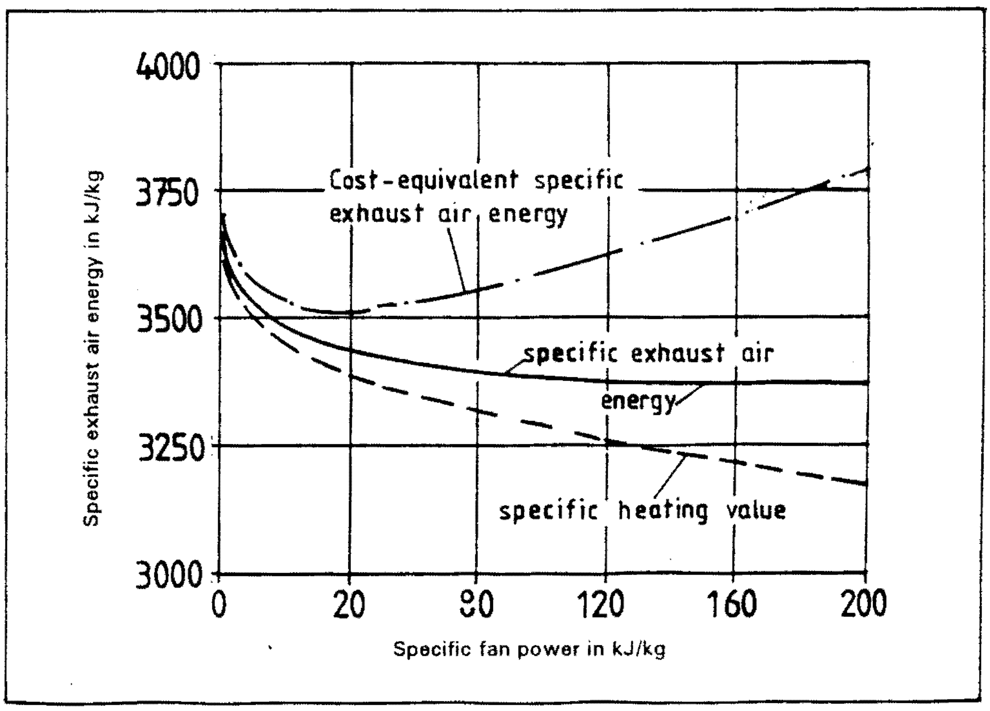


Appendix 2.5

The relationship of ventilation to energy consumption in drying. D.Stahl[89]

Stahl states that electrical enegy costs "at least as much as two to three times the cost of fossil fuel ", in Germany.

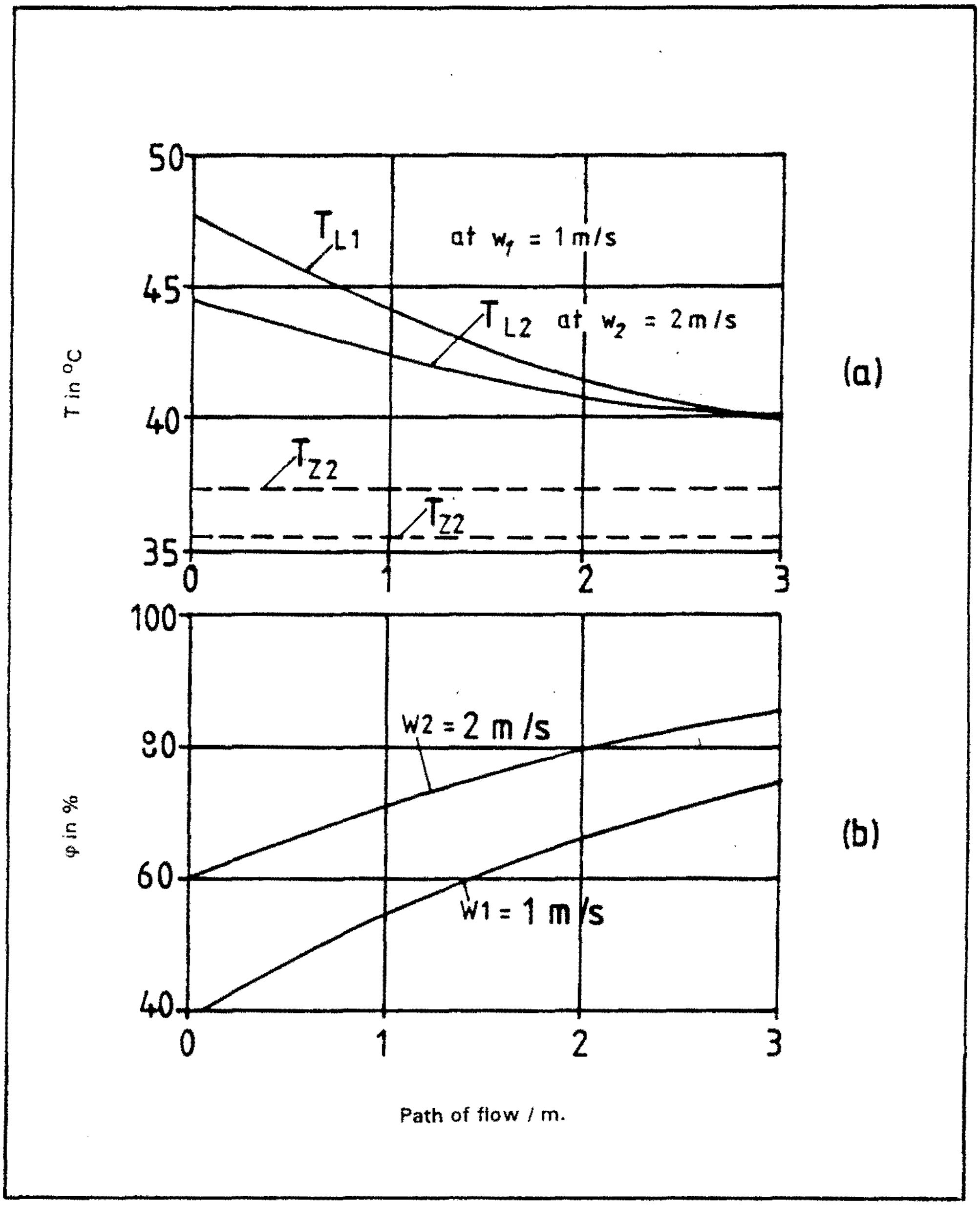
Appendix 2.5(a).



This figure shows the energy requirement plotted against fan energy per kilogram of evaporated water for the stated geometrical and operational conditions.

The full line gives the heat required for the heating and fan power together, the dashed line for the heat energy alone. The chain dotted line comes from the lower curve plus 3 times the fan power corresponding to the extra cost of electricity per unit of energy.

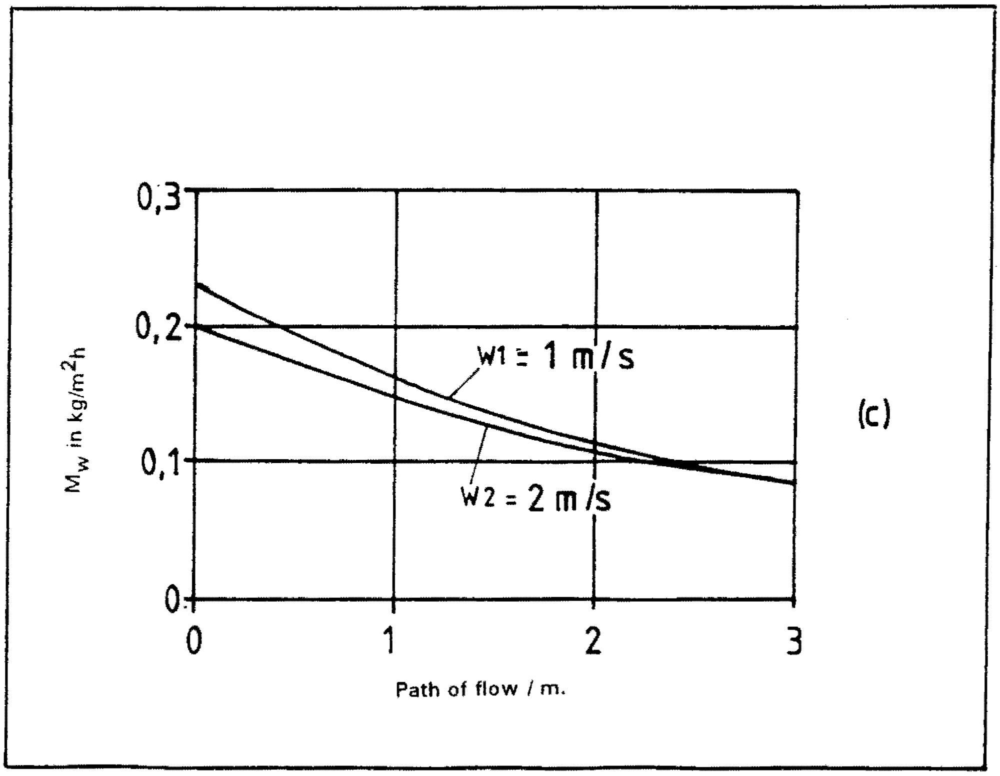
Appendix 2.5(b).



This set of graphs show :

a) The variation of the air temperature T_L and that of the moist product T_Z,

b).the relative humidity φ,



c).the specific speed of drying m_w,

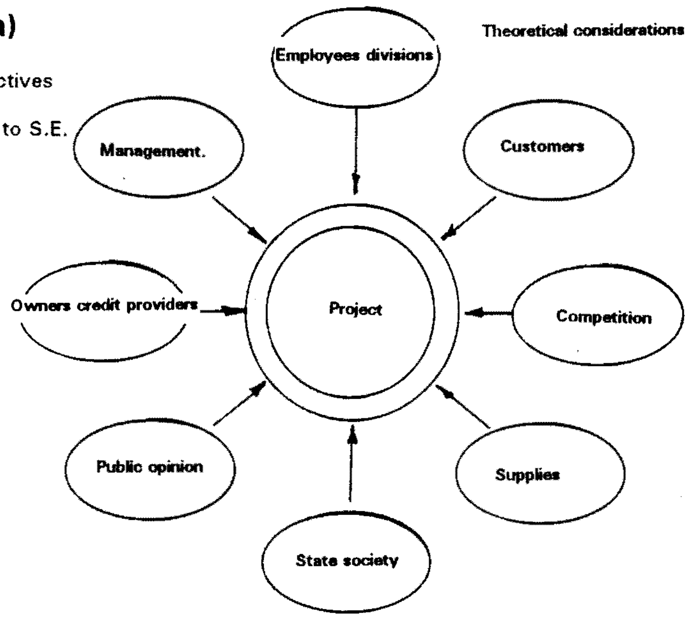
due to the flow through the setting at speeds of w_1 = 1m/s and w_2 = 2m/s.

Stahl indicates that the advantages of the moderating effect of airflow through the setting, as well as reduced drying times, plus other factors compensate for the extra cost of electrical energy. He says that this depends critically on the ratio of electricity to other fuels.

Appendix 2.6(a)

Variables affecting project objectives

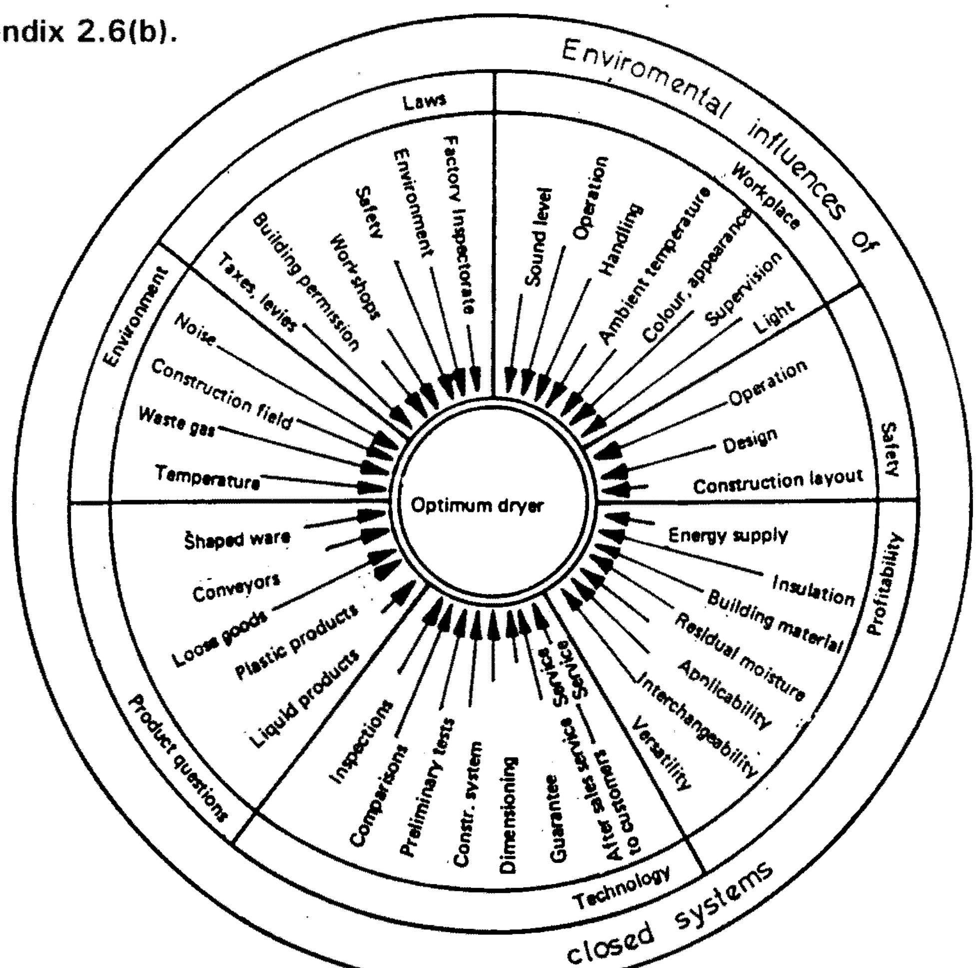
prior to dryer construction acc. to S.E.



Graphic representation

of complex issues. E.W. Schmidt(94)

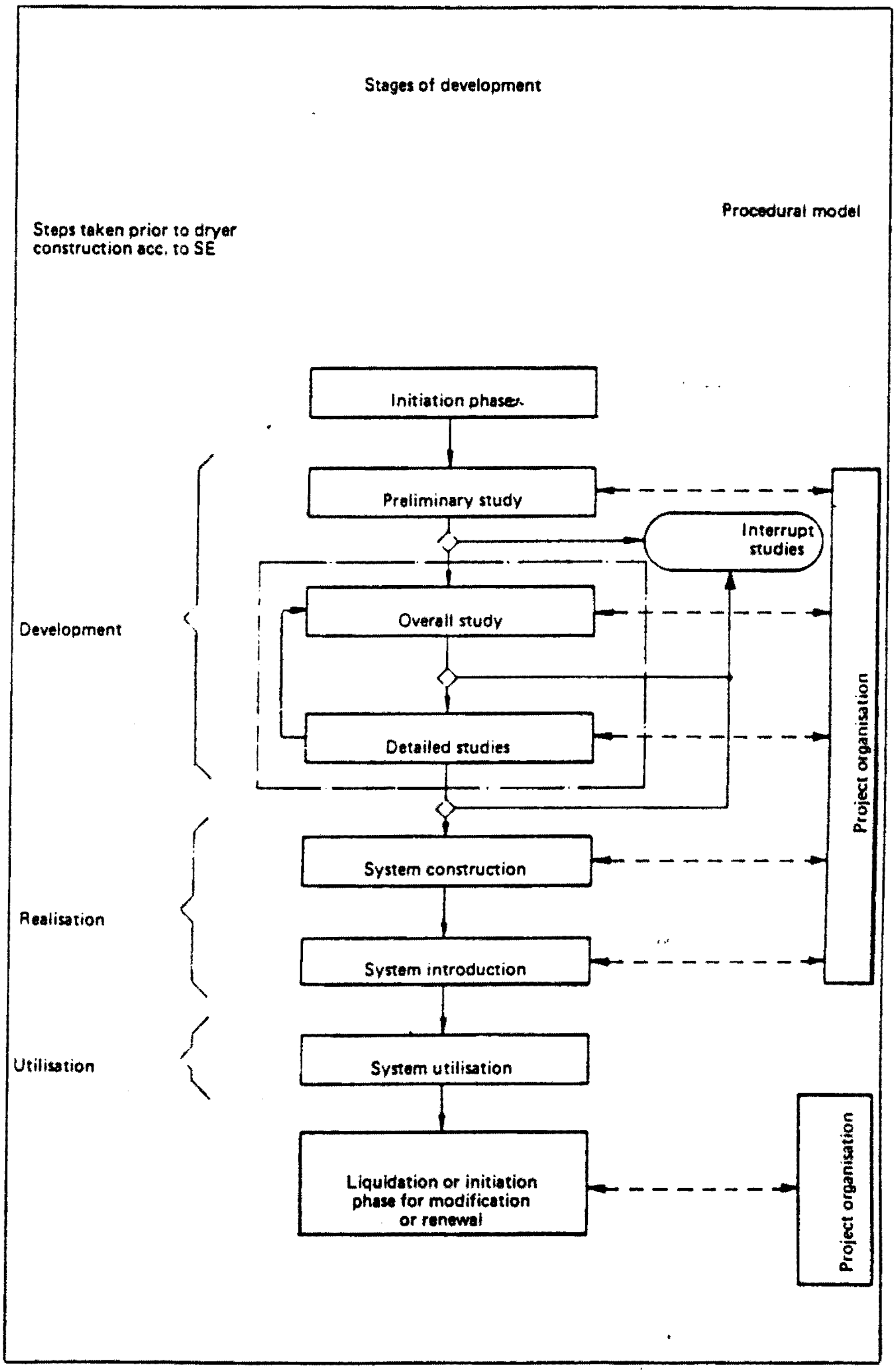
Appendix 2.6(b).



Planning considerations prior to

dryer construction. E.W Schmidt(94)

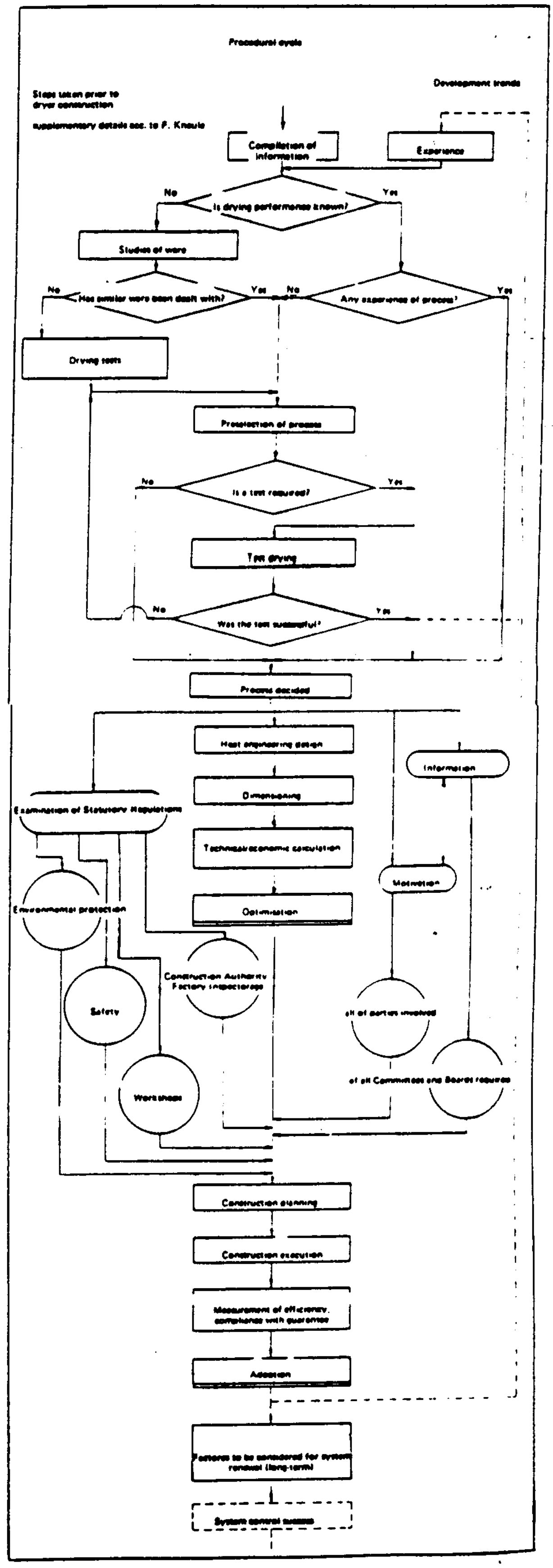
Appendix 2.6(c).



A highly simplified procedural model.

Showing -development,realisation and utilisation. E.W Schmidt[94].

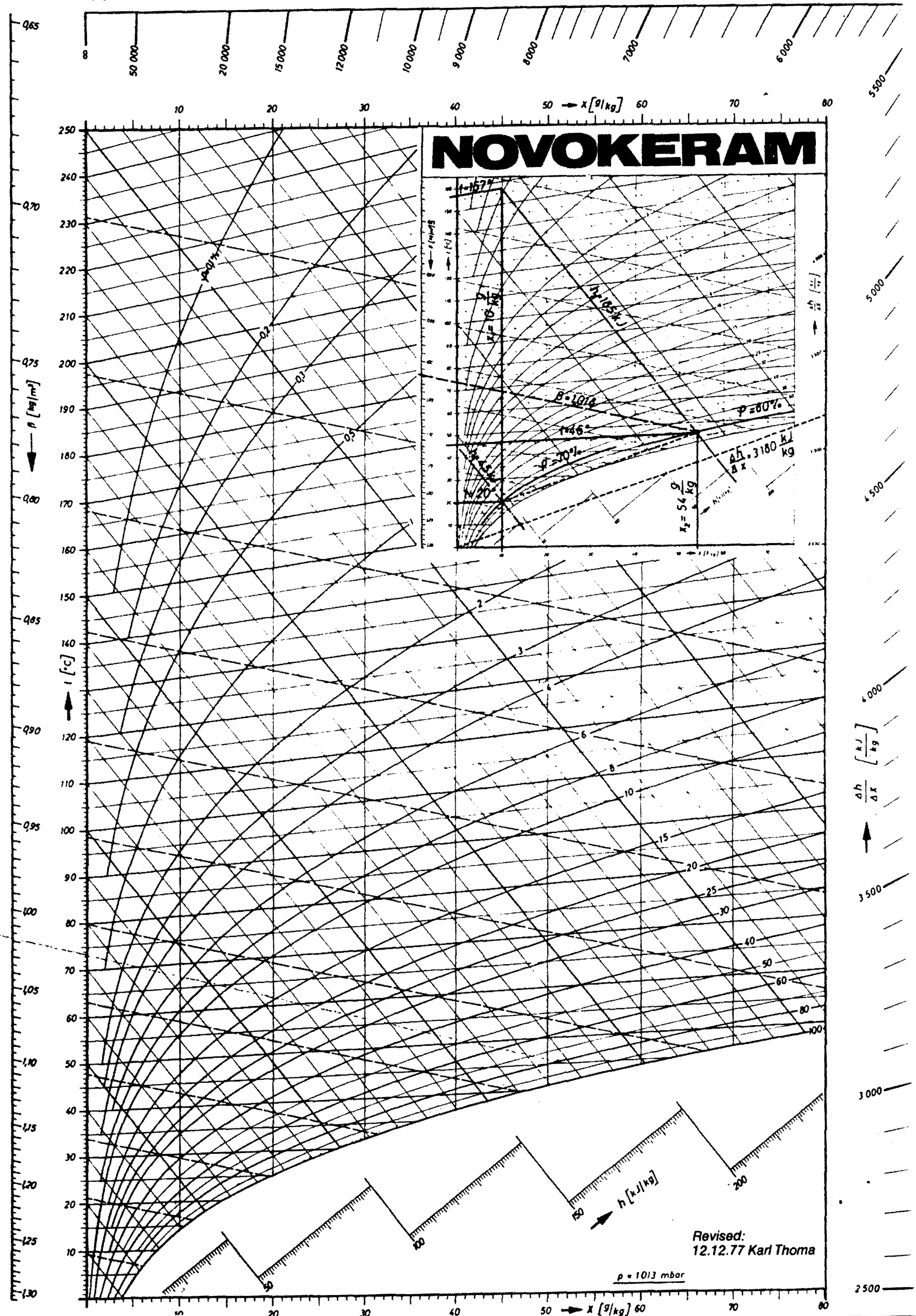
Appendix 2.6(d)



The development trends according

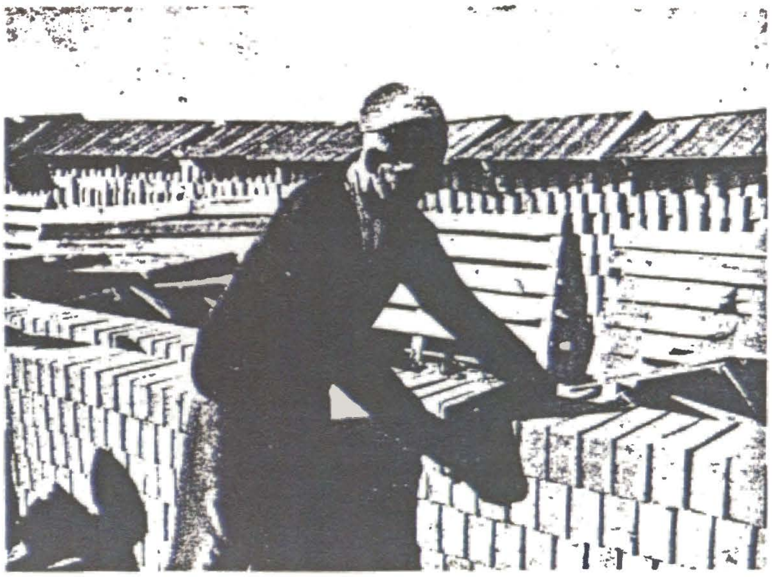
to Industrial practice E.W Schmidt[94]

Appendix 2.7. THOMA[53] *h,x Diagram*



APPENDIX THREE

Appendix 3.1



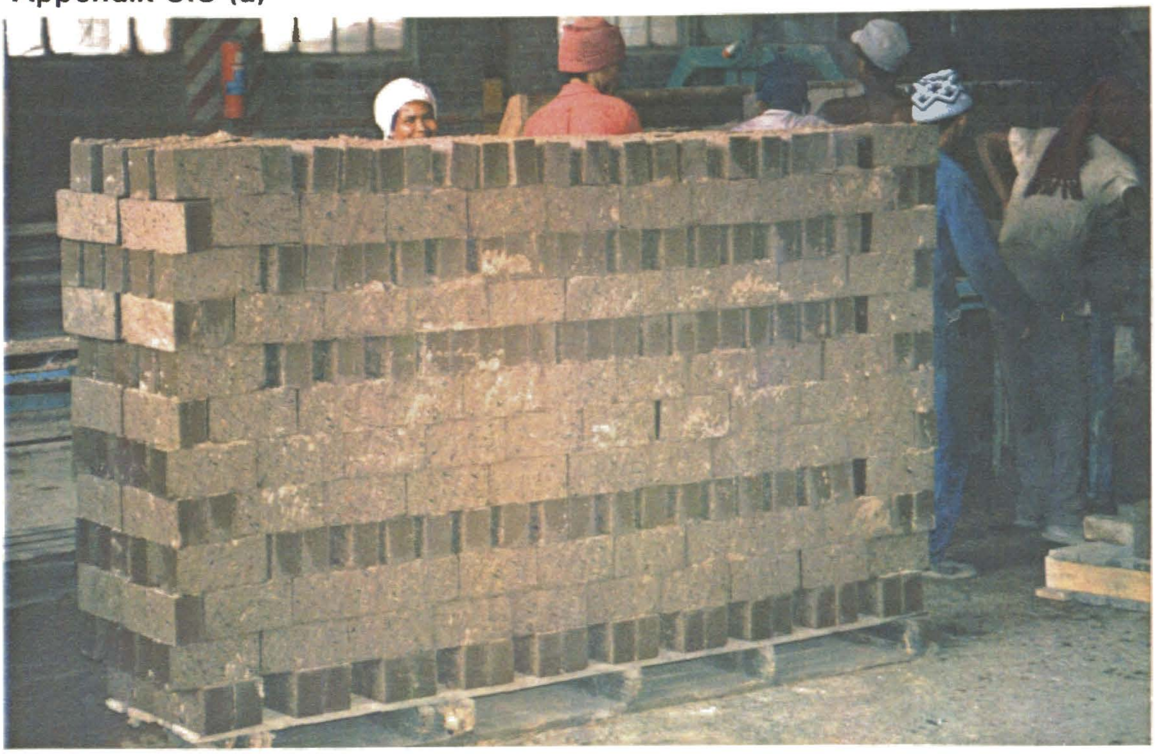
Setting bricks in hack lines.

Appendix 3.2

A Bell FL220 forklift transporting a wooden pallet

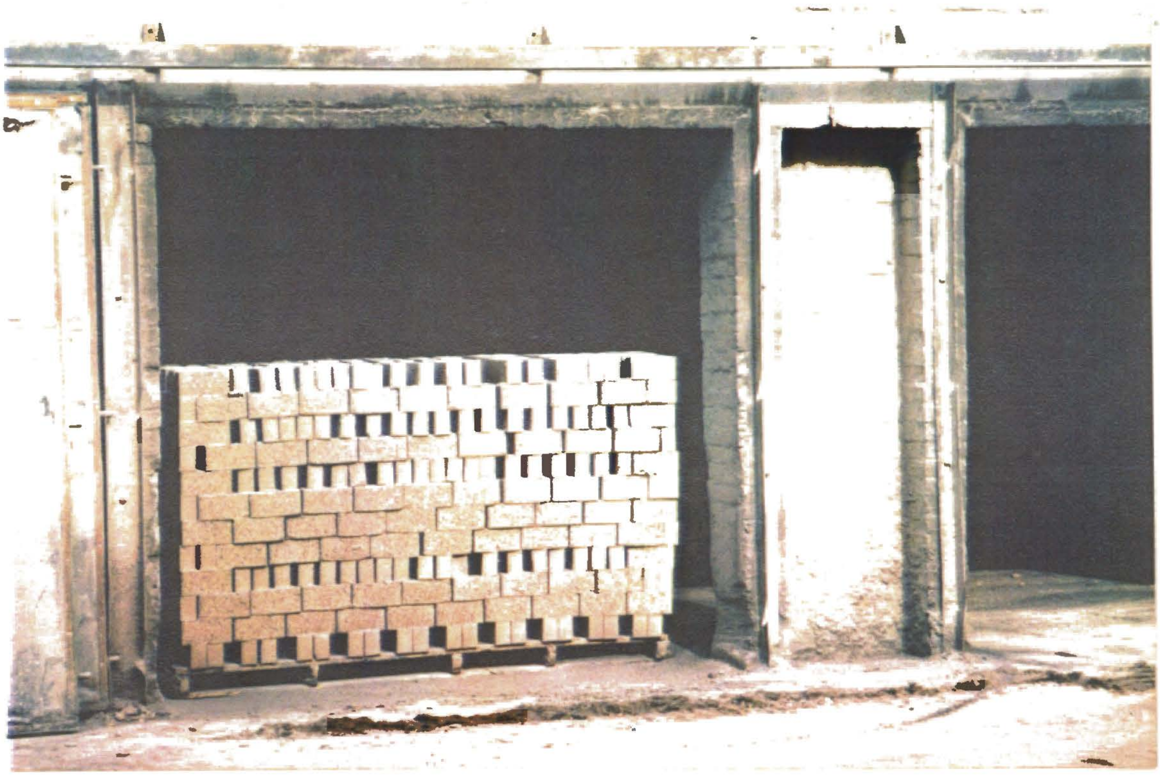
with a with bricks stacked in the "Hulo" configuration

Appendix 3.3 (a)



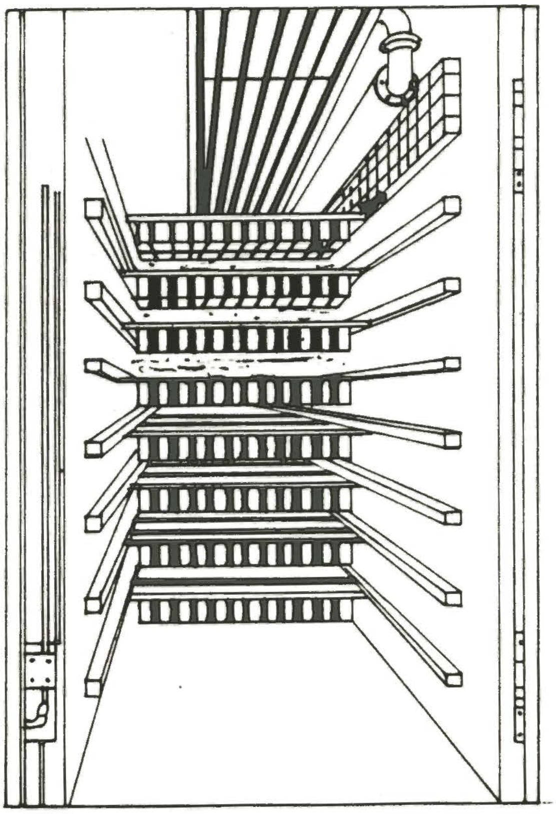
A hulo pack. Sand is spread between the layers of bricks to prevent sticking during the firng process. The layer of bricks on the pallet is set so as to be able to be lifted off the pallet with forklift tynes, for setting in the clamp.

Appendix 3.3(b)



A dry hulo pack standing in the door of a chamber dryer at Corobrik, Koelenhof.

Appendix 3.4



A chamber in a Keller corridor dryer.

APPENDIX FOUR.

Appendix 4.1 Rain damaged pallets

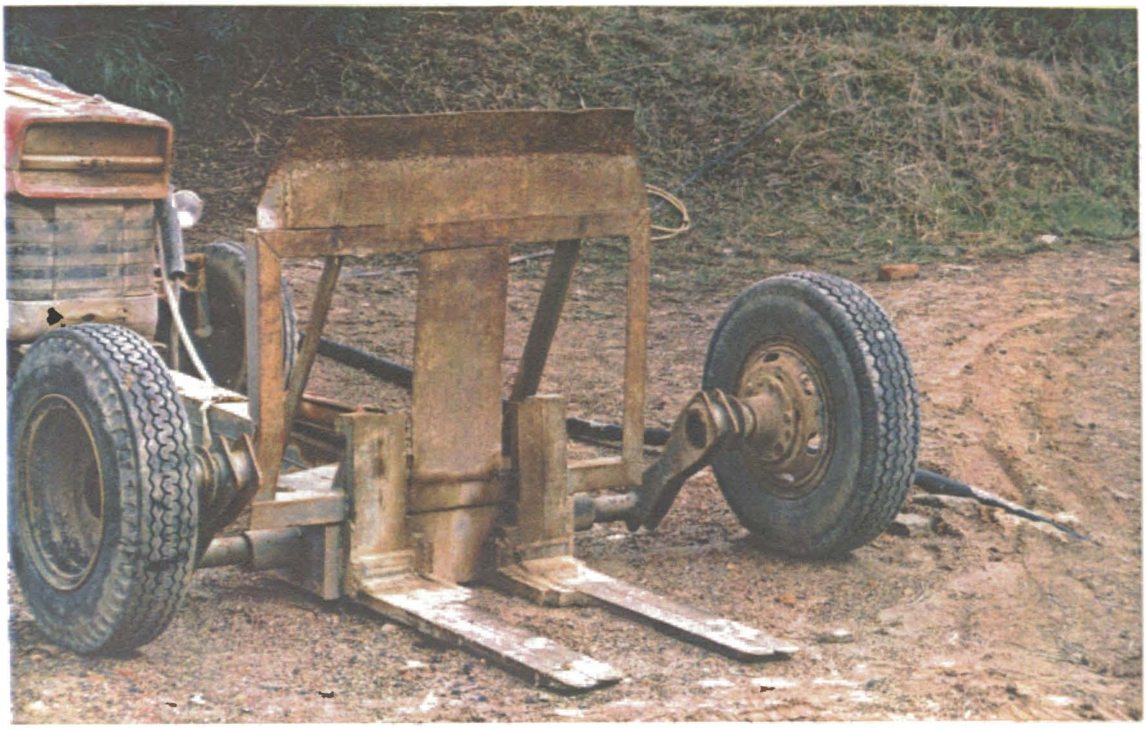
Rain damaged square pallets at Joostenberg Brick April 1993.

Rain damaged square pallets at Joostenberg Brick April 1993

Partially damaged Mc Donald pallets at Joostenberg Brick.

Partially damaged Mc Donald Pallets at Joostenberg Brick

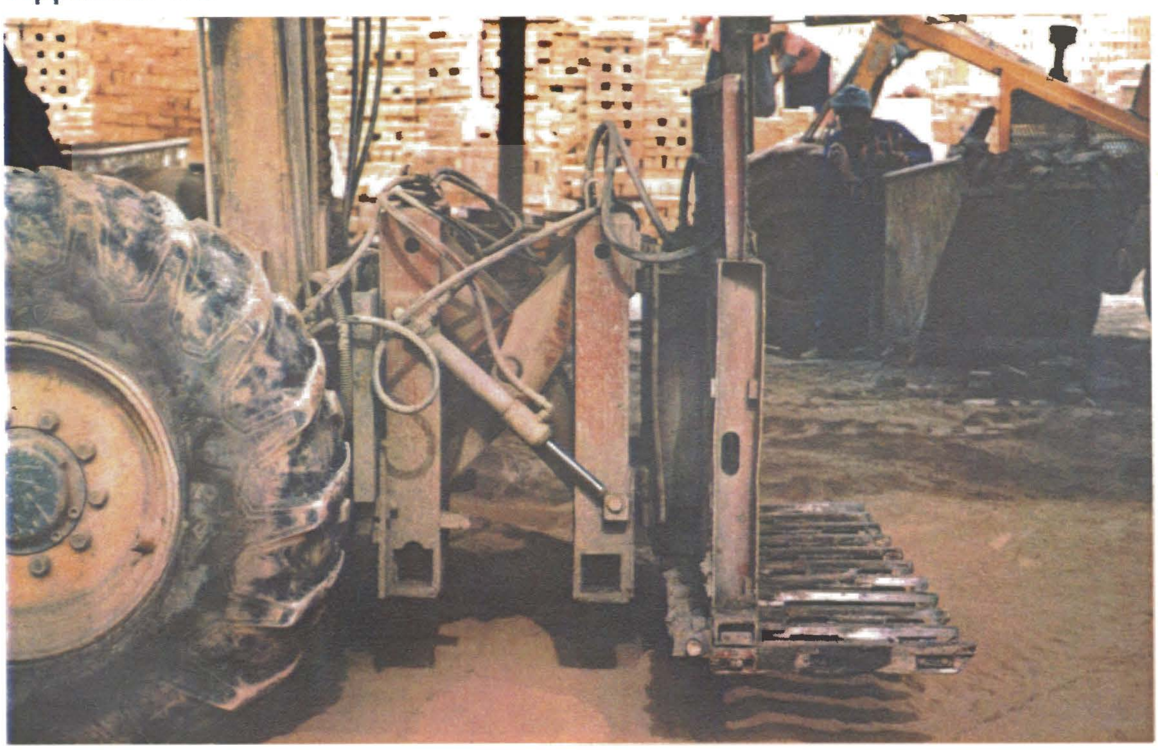
Appendix 4.2



A simple hydraulic lifting mechanism which fits onto a tractor.

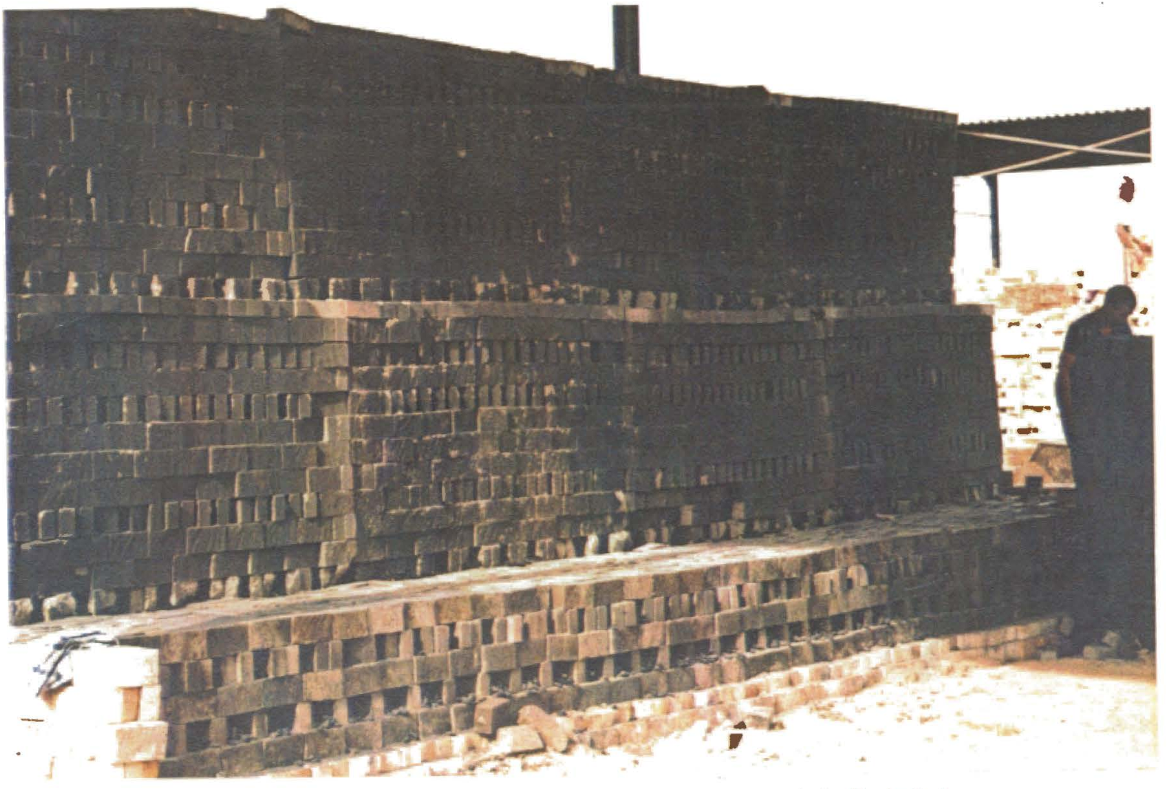
It is usually used with rectangular pallets.

Appendix 4.3



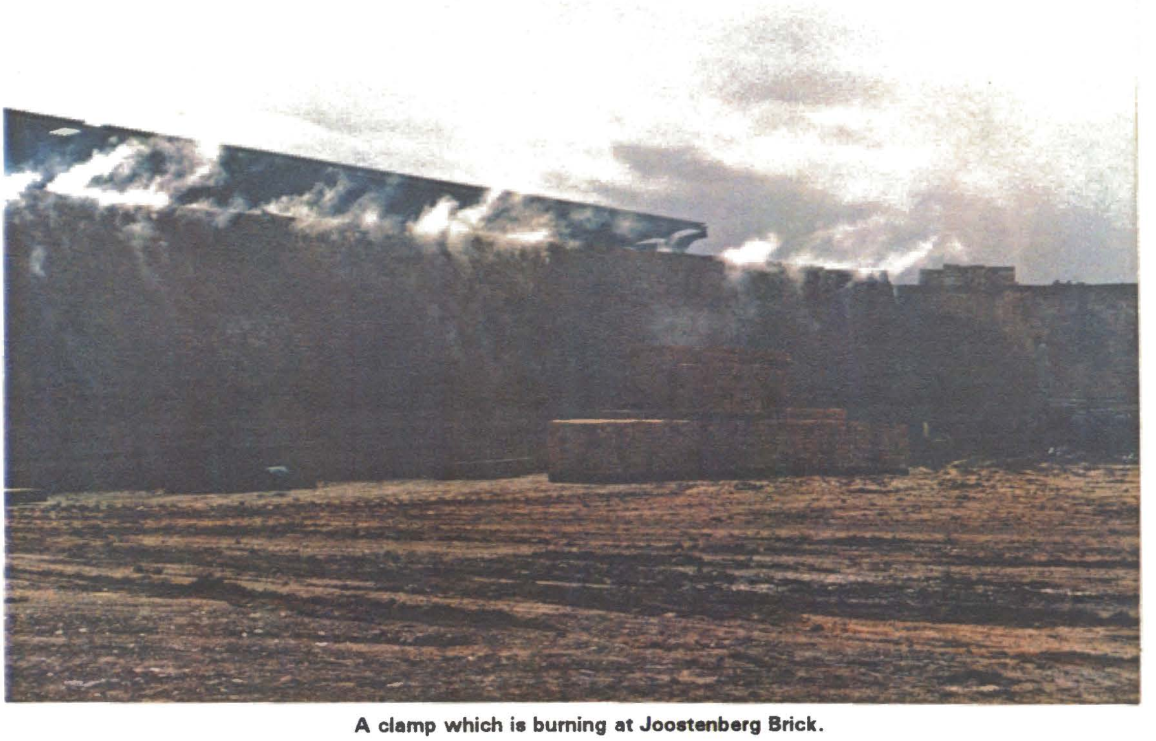
Forklift tynes with an extension mechanism for setting clamps.

Appendix 4.4



A clamp which is in the process of being packed, at Corobrik, Koelenhof.

This clamp is being set by forkilift using the hulo or A.V.H pack.



A clamp which is burning at Joostenberg Brick.

Appendix 4.5

Hulo or A.V.H. packs being set in a clamp at Corobrik, Koelenhof.

A Bell forklift approaching the clamp.

The hydraulic mechanism is being extended to position the stack of bricks.

Appendix 4.6.

The operating costs of a Bell FL 220 forklift.

FL220 OPERATING COST

OPERATING COST PER HOUR		
FUEL	Litres per hr x Cost per ℓ 6 X R1,21	7,26
LUBRICANTS, OIL & FILTERS		0,73
REPAIRS & MAINTENANCE	0,50 X Amount to be depreciated / Hours useful life 125 265,00 / 15000	4,18
TYRES FRONT	Price of Tyre / Hrs life/Tyre 850 / 4000 X 2	0,43
TYRES REAR	Price of Tyre / Hrs life/Tyre 1035 / 4000 X 2	0,26
DUMPER/TRAILER TYRES FRONT & REAR	Price of Tyre / Hrs life/Tyre X 4	
CONTINGENCIES	0,05 X Purchase Price / Hrs useful life 128 000,00 / 15 000	0,43
OPERATING COST PER HOUR	TOTAL	13,29

TOTAL COST PER HOUR	
OPERATING COST PER HOUR	13,29
TOTAL COST PER HOURMETER HOUR	13,29
COST PER CLOCK HOUR (80% of hourmeter)	10,63
LESS RESIDUAL VALUE AFTER 5 YEARS 25 % of PURCHASE PRICE	
PER HOUR: = Residual Value / Hrs useful life 32 000 / 15 000 CENTS/HOUR	2,13
(Deduct this Residual Value in cents/hour from Total Owning and Operating Cost per hour)	
TOTAL COST PER HOUR	R 8,50

Appendix 4 7

The production and market opportunity which the proposed dryer/setting machine combined with clamp firing of hollow ware offers the "clamp brickyard" in the Western Cape.

The above argument proves that, with the prosed dryer and setting mechanism, and assuming hollow blocks can be fired in clamps, that it will be possible for one factory to produce the entire maxi cement production, in the Western Cape, at a price below the lowest cement maxi selling price. This will still be more profitable than producing solid clay bricks at the September 1992 price of R230 per thousand.

It requires the conversion of one factory producing 2×10^6 solid bricks per month, operating on one shift at present, to continue to produce solid bricks, if they so wished, and to operate the factory for an additional 90 hours per week on maxis, to eliminate the cement maxi production of 5×10^6 maxis per month, as mentioned above. If desireable, the clay maxi opposition can also be removed as their production of maxis is fired in an oil-fired Tunnel kiln, which they claim not to be economically competitive with clamps. This situation would continue until other clay manufacturers adopted the same system or dried outside in summer or used conventional dryers on one shift and fired in clamps.

Appendix 4.8

The "business ethics" issues with regard to the proposed production and pricing of clay hollow ware.

The moral issues are numerous. Alternatives, among others, are eliminating the opposition. This implies the loss of businesses and the loss of jobs, with an advantage to the consumer,. which in the case of housing contracts might well be of benefit to the contractor, rather than the house owner. This, unfortunately, would not mean cheaper low cost housing. Another alternative is to maintain a very good profit and follow the dictum of the 18th Century theologiam John Wesley "Make as much as you can, save as much as you can and give away as much as you can". A third alternative is to convert present production to hollow-ware, maintain levels of production and fit in with the present price structures and benefit from the extra profit margin.

The aim of this paper was to reduce specific energy usage as well as to reduce the use of non-renewable resources, to use capital equipment better and to reduce overall production costs. All of these can be achieved at the cost of jobs in the industry and to the disadvantage of the opposition producers within the masonry industry.

APPENDIX SEVEN.

Appendix 7.1

A Portland Cement Institute Certificate showing the results of a set of compressive strength tests on 12 burnt clay maxis.

Portland Cement Institute
Portlandsementinstituut

Claytile Ltd
P O Box 137
KOELENHOF
7605

New

Date of Test: 01.5.93
Order No: Mr Delahunt

Invoice No: 53214
(Attached to monthly statement)
Product: Clay Hollow Maxi

Project: Not known

SABS ACCREDITATION

The results given in this report were obtained from tests conducted within the scope of **SABS Certificate of Listing - Accredited Test Facilities No.LTF 0004.**

COMPRESSIVE STRENGTH BURNT CLAY MASONRY UNITS
(PCI TEST METHOD 8.5)

PCI Ref	Specimen marking	Mass (kg)	Dimensions (mm)	Compressive strength (MPa)
125/WC 3990	1	2,48	224x88x110	8,1
	2	2,50	225x88x110	12,6
	3	2,44	228x90x110	7,3
	4	2,41	227x88x110	8,0
	5	2,42	225x89x111	9,9
	6	2,47	229x89x110	9,8
	7	2,50	223x86x111	14,0
	8	2,47	227x90x110	10,2
	9	2,48	228x86x110	8,4
	10	2,62	225x87x110	11,4
	11	2,50	225x88x111	10,1
	12	2,48	225x87x110	16,0
			Average =	10,4

For **REGIONAL DIRECTOR**

COMMENTS:

1. This laboratory report relates only to the masonry units tested.
2. Deviation from test procedure: None
3. Refer to SABS 227 Tables 3 and C-1 for acceptance criteria and to SABS 0400, Part K Tables 1 and 2 for suitability for use.
4. This report was prepared by **S F Crosswell** Pr Eng.