Energy Conservation Investment Behaviour of Firms: Business as Usual?

Jacco Farla, Kornelis Blok
Department of Science, Technology and Society, Utrecht University
Padualaan 14, 3584 CH Utrecht, The Netherlands.

1. SYNOPSIS

The developments that led to energy efficiency improvement in the building materials industry are described, and barriers to investing in energy efficiency are discussed.

2. ABSTRACT

To be able to carry out an effective policy to enhance the improvement of energy efficiency in the manufacturing industry, knowledge is required about the behaviour of energy consumers in this sector.

In this paper the developments in two subsectors of the building materials industry are analysed: the cement and the brick manufacturing industry. The analysis starts with a description of the main production steps. This is followed by a historical analysis of the developments of the specific energy consumption. Subsequently an inventory was made of the measures that were available (per subsector) to improve energy efficiency, and whether or not these measures were carried out. These findings were combined with information on parameters like energy prices, energy policy, subsidy possibilities, economic performance, and the availability of information on energy conservation.

In both subsectors, the decrease in specific energy consumption could be attributed for a large part to the replacement of equipment.

We found that lack of information did not play an important role in preventing measures to be taken. Also economic barriers, like stringent investment criteria, did not seem to play an important role in preventing measures from being taken. Barriers that were observed related to the long lifetime of equipment in this sector, the fear for decreased product quality, and doubts about the technical feasibility of measures. The effect of historic government incentives to increase energy efficiency seems low. Requiring detailed energy monitoring of production processes may be a means to stimulate energy efficiency improvement.

3. INTRODUCTION

To be able to carry out an effective policy to enhance the improvement of energy efficiency in the manufacturing industry, knowledge is required about the behaviour of energy consumers in this sector.

In the past, research has been done that analyses the historical development of energy efficiency indicators (like energy intensity and specific energy consumption) on a sectoral level (Jenne and Cattell 1983, Boyd *et al.* 1987, Schipper *et al.* 1992, Farla *et al.* 1994). Such work with a helicopter view provides a better understanding of the overall developments that took place, but does not give much insight in the actual behaviour of decision makers in manufacturing industry.

On the other hand studies and empirical work has been done that tries to evaluate how individual decisions of energy end-users (e.g. investment decisions) are taken and how these are influenced. Both individual investment cases and more extended surveys of larger numbers of decision makers have been described (Allen *et al.* 1983, Sassone and Martucci 1984, Ross 1986, Gruber and Brand 1991, U.S. Congress 1993, Velthuijsen 1993, Burke 1994, Gillissen and Opschoor 1994). Although this work has improved our understanding of decision making on energy efficiency investments (e.g. the influence of knowledge on investment behaviour, the pay-back-periods required, etc.), a number of questions remain unanswered. For instance, it remains unclear if we can explain the developments observed with a helicopter view from individual decisions. It is especially not clear what type of decisions are most important for the improvement of energy efficiency.

In order to clarify this, it seems useful to carry out (long-term) analyses in specific sectors in which the decisions that influence the energy efficiency of a sector are mapped and analysed.

The aim of this paper is to carry out such an analysis for two main segments of the building materials industry in the Netherlands.

4. METHODOLOGY

In this paper the following approach is followed for two subsectors of the building materials industry in the Netherlands. First, the subsector and its main production processes are described, mainly on the basis of information found in the open literature. Then, a historical analysis is made of the development of the specific energy consumption for the sub-sector as a whole. Subsequently, an overview is made of the actions that were available to improve the energy efficiency and whether, or to what extent these actions were carried out or not. For each of the possible measures estimates are made of potential savings, required investments, pay-back-periods, etc. The information is obtained from earlier inventories of energy efficiency improvement options, carried out in our department (De Beer *et al.* 1994) and additional literature study. Additional information, including information about the actual actions taken, is obtained from representatives from the sector. Due to space constraints this information is presented in a very summarized fashion.
Finally, we try to answer the following questions on the basis of the information obtained:

- Does the set of actions actually taken explain the observed behaviour of the sector as a whole?
- Can the actions that were taken be broken down in various categories? We will make a breakdown representing the type of investment, e.g.:
  1. operational changes requiring no major investments.
  2. add-on (or retrofit) investments with an energy efficiency improvement effect, but mainly carried out for other purposes;
  3. add-on (or retrofit) investments mainly carried out for the purpose of energy efficiency improvement;
  4. full replacements of production equipment (generally not carried out for the purpose of energy efficiency improvement alone);
- Which barriers can be identified for improving the energy efficiency? In general three types of barriers are distinguished:
  1. lack of knowledge about energy efficiency improvement;
  2. investments are not found profitable enough;
  3. other barriers.

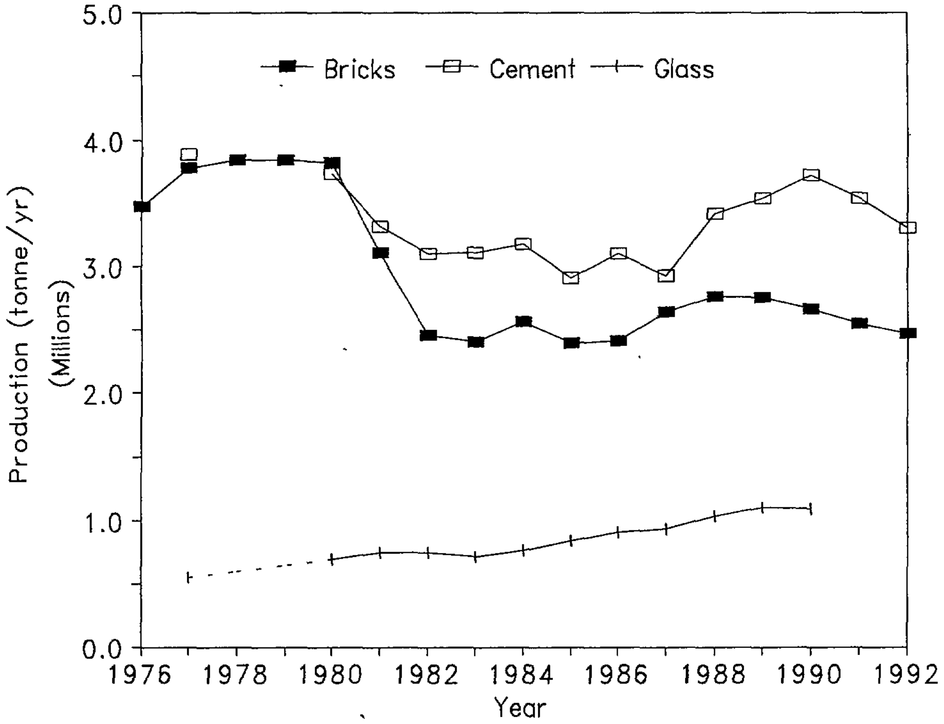
  We will discuss whether each of these barriers prevented or delayed action. For the last two categories we also use data on investment projects that are currently being considered or carried out. This part of the analysis will have an exploratory character.
- We will discuss in what way government incentives influenced investment behaviour.

5. SHORT INTRODUCTION TO THE BUILDING MATERIALS INDUSTRY

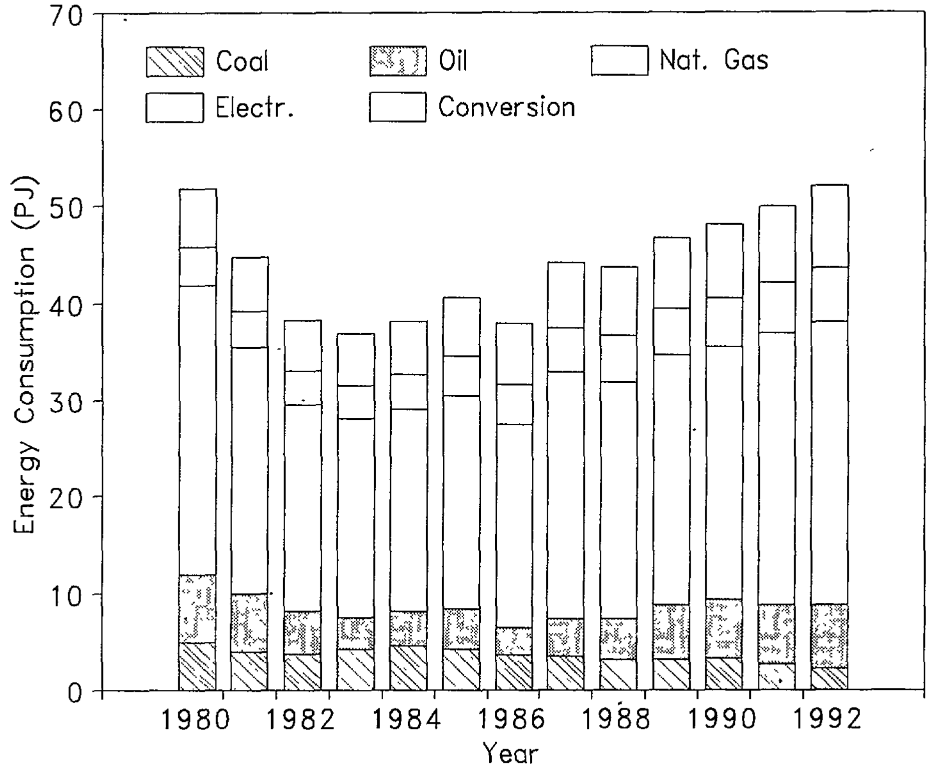
The demand on primary energy in the building materials industry amounted in 1990 to nearly 50 PJ (CBS 1991). This corresponds to 4% of the primary energy consumption in industry, including feedstocks (Farla *et al.* 1994). The energy intensity (ratio of primary energy consumption and value added) amounted to 13.8 MJ/Dfl.[1], which is slightly higher than the energy intensity of the total Dutch industry, which is 12.2 MJ/Dfl. (Farla *et al.* 1994). Over 75% of the primary energy consumption in 1990 was consumed in the following three subsectors:

- Bricks and roofing tiles;
- Cement, limestone and other mineral products;
- Glass.

1044 firms were active in this sector of industry in 1990, with over 37000 employees (CBS 1993). Ten percent of these firms used over 80% of the total energy consumption in the sector. In figure 1 we give the production volumes of bricks, cement and glass, from 1976 to 1992, and the developments in energy consumption.


Bricks
Cement
Glass
Production (tonne/yr)
(Millions)
5.0
4.0
3.0
2.0
1.0
0.0
1976
1978
1980
1982
1984
1986
1988
1990
1992
Year

Panel 3



In figure 1 we see a production decrease of bricks and cement in the early 1980's due to an economic recession. We calculated the overall developments in the specific energy consumption with data from Farla *et al.* (1994). Between 1980 and 1990, the specific electricity consumption in the building materials industry rose with 14%. In the same time, the specific fuel consumption decreased with 8%^{2}.

In this paper we focus our attention at two parts of the building materials industry; the cement industry, and the brick manufacturing industry.

6. THE CEMENT MANUFACTURING INDUSTRY

6.1. Introduction

Cement is one of the most important building materials, mainly as an ingredient of concrete. The manufacturing of cement is a large-scale industrial process in the Netherlands. The cement production in both 1980 and 1990 was 3.7 million tonne (CBS 1985/1988/1993).

In the Netherlands, only one cement company is active which operates three plants. The company is a subsidiary of a Belgian and a German cement manufacturing company. Only in one plant in the Netherlands the total production process (including the production of clinker) is carried out. In the other two plants only mixing and milling of the cement ingredients takes place. The total Dutch cement consumption (5.5-6 Mton/yr) is covered for approximately 60% by domestic production. The remaining 40% is imported, mainly from Belgium and Germany.

6.2. Process description

The main raw materials for the manufacture of cement are limestone, clay minerals, silica sand and energy carriers (Fog and Nadkarni 1983). All cements contain (portland) clinker which is produced by thermal processing of limestone together with other inorganic substances. Clinker can be partially replaced as a cement ingredient by fly-ash or blast furnace slag. Four kinds of cement are produced in the Netherlands: portland cement, portland/fly-ash cement, blast furnace cement, and masonry cement. The composition of these four products is given in table 1 (Van Duin 1981, Smit 1993, Maaskant 1994). In this table we also give the production distribution in 1977 and 1992.

Table 1. Cement ingredient content and production in 1977 and 1992 per type of cement.

	Portland cement	Portland/fly-ash cement	Blast furnace cement	Masonry cement
Production (ktonne)				
1977	1595	_	2300	_
1992	890	350	1970	90
Ingredients (% w/w)				
Portland clinker	95	70	23	50
Gypsum/anhydrite	5	5	5	3
Fly-ash	_	25	_	_
Blast furnace slag	_	_	72	_
Limestone	_	_	_	47

The cement production process can roughly be separated in three production phases: raw material preparation, clinker production (pyroprocessing), and finish grinding. Much electricity is used in the first and third step. Most of the fuel input in the production process occurs during clinker production.

6.2.1. Raw material preparation.

In the Netherlands the limestone (marl) is extracted by open air mining with the aid of explosives. The lumps of marl are precrushed and transported by conveyer belts to a storage site. The marl is preblended before it enters the clinker production process. Clinker can be produced in a wet or dry production process. For the wet process, the marl is ground together with water. In the dry process the marl is first dried and then ground. Grinding of the raw materials to a slurry or `raw meal' takes place in ball mills.

6.2.2. Clinker production.

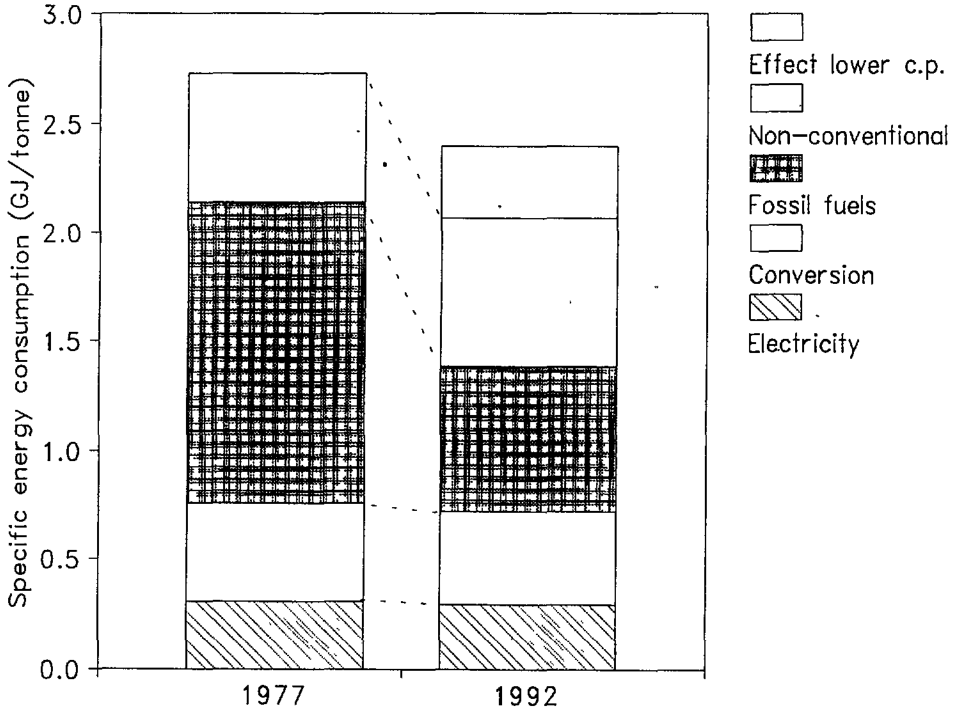
The raw materials are pyroprocessed to clinker in a rotary kiln. In the wet process, the slurry of raw materials is introduced in the kiln. There, the water evaporates, CO_2 is released (calcination) and clinker is formed while the slurry is slowly transported to the sintering zone by the rotation and inclination of the kiln. In the dry process, the raw meal is preheated to 700°C in cyclone preheaters with the exhaust gases from the rotary kiln (900°C). In the kiln, calcination takes place and clinker is formed. The clinker is quickly cooled in a clinker cooler with air. The kiln may be fired with any kind of fuel; gaseous, liquid or solid.

6.2.3. Finish grinding.

For the production of cement, the clinker and other ingredients are mixed and ground. Grinding takes mainly place in ball mills. The ground product from the ball mills is screened in a classifier: particles that are too large are recycled to the mill entrance. The fineness of the particles is of importance for the hardening strength of the cement: smaller particles yield higher strenghts. Finer cement also needs more electric energy because a larger share of the mill output will be recycled.

6.3. Development of specific energy consumption

The specific energy consumption was calculated for the years 1977 and 1992. The energy consumption in 1977 was derived from ENCI (1977), with additional information from Krekel *et al.* (1982) and Van Duin (1981). The energy consumption in 1992 was derived with the figures from Dassen (1994), taking into account the ratio of fossil fuels and non-conventional fuels for the clinker production (70%) (Lanser 1994). Additional figures were taken from Smit (1993), and data on the two CHP plants were derived from Krachtwerktuigen (1991), Baumann (1994), and Maaskant (1994).
We considered the following fuels as `fossil fuels': natural gas, oil, and brown coal. Slate, and products from refineries and chemical industries are indicated as `non-conventional'. The consumption of electricity from the national grid was converted to demand on fossil fuels by assuming a national generating efficiency of 40% (indicated with `conversion'). The results are depicted in figure 3.



It should be noted that the SEC's in figure 3 are calculated from the actual energy consumption and cement production figures for the Netherlands; the energy embodied in imported clinker is not taken into account. In 1977 over 30% of the clinker was imported (Van Duin 1981), in 1992 this figure had risen to over 40%. Furthermore, the clinker content of the produced cement decreased between 1977 and 1992 from an average content of 54% to 48% (cf. Table 1). This was caused by an increasing production share of the low clinker cements like portland/fly-ash cement and blast furnace cement. The production share of the latter is over 60% in the Netherlands; the highest in the world. The result is a decrease of the ratio of clinker production to cement production from 0.36 to 0.27. This change is responible for a 12% decrease in SEC. The remaining nearly 12% decrease in SEC can be attributed to a more energy-efficient production process. This indicates that the energy efficiency increase per year amounted to 0.8%. The `fossil fuel' consumption per tonne of cement decreased 35% between 1977 and 1992 (a rate of nearly 3% per year).

6.4. Evaluation of the developments in energy efficiency in the cement industry

In this section we give the energy conservation measures that were considered or implemented between 1977 and 1992. The main measures leading to energy conservation concern the production of clinker (savings of fuel) and the finish grinding of the cement (savings of electricity). Data on these measures are given in table 2.

Table 2. Overview of energy conservation projects in the cement industry

		Energy conservation				Pay-back period			
Conservation measure		Savings (%)	Potential (PJ$_p$)^a	Energy carrier	Investment (Million Dfl.)	Energy (yr)	Total^b (yr)	Implemented (PJ$_p$)^a	Year of Implementation
Clinker production									
Introduction of dry process	replacement	>20^c	0.6^d	fuel	150-200^e	>25	?^{f}	0.6	1968-1990
Feed preheater^g	retrofit	2.5	0.2	fuel	32	>25^h	?^{f}	0.2	1984
Advanced process control^i	retrofit	3	0.1	fuel	1	4	1	0.1	1994
Slag addition^j	oper. change	3	0.1	fuel	n/a	n/a	n/a	0.1	?
New kiln	replacement	13^k	0.5^k	fuel	200^l	>25	?^{f}	–	
Finish grinding									
High efficiency classifier	replacement	18^m	0.3	elec.	3^n	3	3^o	0.1	1991, 1992
Roller press (semi-finish)	replacement	30^p	0.5^q	elec.	68^r	>25^r	>10^r	0.2	1995
Roller press (finish)	replacement	45^s	0,7	elec.	10^t	3-10	?^{f}	–	
Increase milling additives	oper. change	13^u	0.2^v	elec.	n/a	n/a	n/a	0.2	1985-1990
Other measures									
Management info system^w	retrofit	?	?	f/e	?	n/a	n/a		1994-
Slag drying with CHP	retrofit	25^x	0.2^y	elec.	25^z	3	3	0.2^A	1981, 1984, 1994^B

(a) Electricity is converted to demand on primary energy carriers by multiplying with 2 5, (b) With total Pay-back period we mean the PBP when taking also quantifiable non-energy benefits into account; (c) Derived from (Holderbank 1993); (d) Based on a production capacity of 1000 ktonne clinker, assuming the shares wet process/dry process = 60/40, and assuming a SEC of 5 GJ per tonne clinker for the wet process, and 4 GJ/tonne for the dry process in 1977, (e) Estimate from (Krekel *et al* 1982); (f) Non-energy benefits unknown, (g) Data from (Dassen 1995); (h) Calculated with a fuel price of 3 Dfl/GJ; (i) Data on this measure were derived from (Juijn 1994) and (TIEB 1994), (j) Data from (Dassen 1994, Lanser 1994); (k) Figures calculated for a 1000 ktonne/yr capacity, with present SEC of 3.6 GJ/tonne clinker (Dassen 1994), and an achievable SEC of 3.1 GJ/tonne (Holderbank 1993, Anon 1994a, Anon. 1994b), (l) Estimate by (Gulikers 1994), (m) Derived from (TIEB 1993, Gulikers 1994), (n) Investment figure from (TIEB 1993), for a capacity of approx. 600 kton/yr, (o) Lower PBP possible, because of lower share of clinker needed for blast furnace cement (TIEB 1993); (p) Estimated electricity savings based on (Gulikers 1994); (q) Based on the electricity requirement for milling of 200 GWh, derived from (Baumann 1994, Gulikers 1994, Maaskant 1994), (r) The investment figure of 68 Mln Dfl. relates to one specific investment project. Annual savings are estimated to amount to 2 Mln Dfl. for electricity, 2.5 Mln Dfl for labour costs, and 1.5 Mln Dfl for savings on maintenance costs (Gulikers 1994); (s) Derived from (Gulikers 1994); (t) Estimate on the basis of (Holderbank 1993, Gulikers 1994); (u) Data from (Maaskant 1994); (v) The savings are extrapolated to the total electricity consumption for milling; (w) No estimates available on potential energy savings and investment costs, (x) Energy savings estimated on the basis of (Anon. 1981, Krachtwerktuigen 1991); (y) Potential calculated for 1400 ktonnes of slag (1992), and a heat consumption of 0.7 GJ/tonne of wet slag (Van Duin 1981, Van Dijck 1991), (z) Estimated for a total capacity of 19 MW$_e$, on the basis of actual investment figures for a 3 2 MW plant (Anon 1981), and a 12 MW plant (Klein 1994); (A) 80% of the CHP capacity for slag drying is implemented, based on the blast furnace production figures for 1992; (B) In 1994, a 3 2 MW$_e$ CHP plant (1981) was replaced with a 4.8 MW$_e$ CHP plant (Baumann 1994, Senter 1994a).

6.4.1. Changes in the specific energy consumption.

Between 1977 and 1992 the specific energy consumption decreased with nearly 1% annually. The measures described in table 2 can - to a large extent - explain the observed reduction in specific energy consumption.

Besides the developments that led to the decrease in specific energy consumption, there are also developments that increased the specific energy consumption. The fuel switch from natural gas to brown coal between 1977 and 1979 led to an increase in the specific fuel consumption (Krekel *et al.* 1982). The switch to the dry process led to an increase in the grinding electricity consumption of the raw materials (Krekel *et al.* 1982). The use of advanced dust removing equipment, and the use of (dust-free) pneumatic transport systems have also led to an increase in the specific electricity consumption (Lanser 1994). Incidentally, the change in compostion of the blast furnace slag led to the necessity to grind the cement finer to reach the same strength properties (Maaskant 1994). This led to an increase in the specific electricity consumption for finish grinding of blast furnace cement in one plant of over 10%.

6.4.2. Classification of the developments.

What category of actions was most important to achieve the observed decrease in specific energy consumption? As can be deduced from table 2 most reduction in specific energy consumption resulted from replacement investments.
It should be noted here that the distinction between retrofit and replacement is sometimes not made in the cement industry, and that replacement investments are not always "autonomous", but are also held against the profitability criterion.

The largest 'replacement' that occurred in the view period was the wet-to-dry process conversion. After installation of a long dry kiln in 1968, the production capacity in the wet kilns was reduced by taking these wet kilns out of operation one by one. The capacity increase of the dry kiln may also be seen as part of this replacement strategy.
It can be argued that the wet-to-dry conversion also led to substantial savings in labour costs. The number of people involved in the production of cement decreased from 1500 in 1977 (Krekel *et al.* 1982) to 700 in 1994 (Lanser 1994). It also led to further automation and mechanization of the production process. The replacement of ball mills with a large roller press will also yield large savings in labour costs (Gulikers 1994, Maaskant 1994). These savings outrange (financially) the savings in energy costs (Gulikers 1994).

New environmental requirements are often incorporated in the large replacement projects. For instance, in the case of the roller press semi-finish grinding system, dust emission controls that would otherwise have been necessary on the existing ball mills are made superfluous by a new installation with state-of-the-art dust emission control (Gulikers 1994). It may even be argued that environmental requirements accelerate large replacements, because part of the investment costs can be attributed to these necessary investments, and are not held against the profitability criterion.

None of the measures that lead to energy efficiency improvement were implemented for the sake of energy conservation alone, except the introduction of combined heat and power. In all other cases, other benefits have been part of the decision process.

6.4.3. Barriers: knowledge of energy efficiency improvement.

We describe how information on energy conservation may reach the cement industry. It should be noted that energy is very important to the cement industry, because of the large energy costs. In 1977, labour and energy costs were 28% and 22% of the production costs, respectively (derived from Krekel *et al.* 1982). Energy costs nowadays make up approximately 30% of the production costs (Lanser 1994).

Severe competition between the firms in a sector may be a reason for restricted information supply on new techniques and developments. Such competition does not exist within the Netherlands. The Dutch cement manufacturers serve approximately 60% of the domestic market for cement. Because of the low value added, road transportation of cement over long distances is not economic. Therefore the market is restricted to a few hundred kilometers around a cement plant (Krekel *et al.* 1982). Some competition exists with Belgian and German manufacturers. Unlike many other industry branches, market expansion is hardly possible for cement manufacturers. Therefore, the main route to increased profits is by decreasing production costs.
Because the Dutch cement plants are part of one company, free information exchange exists between these plants. Information is also gathered from the firm's parent companies in Belgium and Germany (Lanser 1994). Furthermore, the exchange of technical information between still other firms is good (Gulikers 1994, Lanser 1994).

Besides information exchange with other firms, information is derived from the international literature by a technical studies department. There is no research institute in the Netherlands that specialized in cement manufacturing. Much information is also derived from the suppliers of equipment (Lanser 1994).

6.4.4. Barriers: investment procedure and profitability criterion.

Since the three Dutch cement plants are operated by one company, the formal procedure for investments is the same. The procedure for investment decisions is as follows (Jacobs 1994).
No distinction is made between investments to reduce energy consumption and other investment projects; most investment projects lead to a reduction in specific energy consumption. Depending on the size of the project, decisions are taken at different levels of the company. Investment projects under Dfl. 100,000 are decided upon by the plant manager. Between Dfl. 100,000 and 500,000, the central director of the Dutch cement division has to agree with the investment, and above this amount of money the decision is taken by the parent companies (in Belgium or in Germany). Furthermore, the three cement factories in the Netherlands each make an annual investment schedule for the next three years. For large investment projects, a distinction is made between replacement, improvement, expansion and strategic projects, though distinction is not always possible.
All the money for investments comes from the company; there is no individual financing system per plant. Subsidies are included in investment proposals. Investment projects are prepared by ad-hoc project teams. These teams typically consist of the plant director, an engineer/technician and someone for the financial details. As a rule-of-thumb investment projects are approved of if the internal rate of return (IRR) exceeds 15%. For the calculation of the IRR, an economic lifetime of 5 or 10 years is assumed, and a rest value is attributed to the asset after this period.

As pointed out, large investment decisions have to be approved of by the Belgian company directors in Brussels. This may take some time (2-3 years), and large investment projects normally take over 5 years, between the project start and the actual date of implementation (Gulikers 1994, Maaskant 1994).

Because of the efforts of the cement industry to use wastes and non-conventional fuels, the fuel costs for the clinker production are now relatively low. It is estimated from (Juijn 1994) that the fuel costs are less than 3 Dfl/GJ. This, and the relatively low cost of electricity (Gulikers 1994), limits the profitability of energy saving projects.

Some energy conservation in the view-period was achieved by operational changes and small retrofit projects. The pay-back periods for the small retrofit measures seem to be consistent with the stated requirement for the profitability.
We observed that the energy-related pay-back period is not very important in the cement industry. Other benefits and considerations (labour costs, quality aspects) are usually much more important reasons for investments, and energy conservation is a by-product of these investments.

6.4.5. Other barriers.

Other factors that influence investments in energy conservation relate to the large scale of the production processes, the resources situation, and expected influences on the product quality.

Cement production is a large-scale process, with large-scale equipment and matching costs. Most equipment has a very long lifetime. This holds for kilns as well as for mills. With the proper maintenance, which includes the replacement of wear-sensitive parts, these pieces of equipment may last over 30 years. The last wet kiln, when taken out of operation, was 39 years old. The long dry kiln now in operation is 26 years old. The average age (capacity-weighted) of six ball mills in one cement plant is now 25 years.

In the Netherlands marl is used as the limestone ingredient of clinker. The deposit from which the marl is extracted is limited. Efforts of the cement industry to gain mining concessions for other deposits (Margraten plateau) were not rewarded. This uncertainty of future resources led in the 1980's to postponement of replacement investments (Krekel *et al.* 1982).
At the moment the marl resource is secured until 2025. Because the marl availability after 2025 is uncertain, this may again make the cement industry reluctant in financing large replacements (e.g. replacement of the kiln with a nearly 15% more energy effcient kiln).

The cement industry has to observe several emission requirements, for SO_2, NO_x and airborne dust. Emission control has led to extra energy consumption. For instance, dust emission standards require large dedusting equipment, that consume electricity.

The quality of cement is a.o. measured by the strength it develops. According to the cement industry, cement should be of constant quality (Maaskant 1994). This means that changes in the production process must be compatible with keeping the customers satisfied. For instance, some customers were notified of the installation of a high efficiency classifier because of possible influences on the product (Baumann 1994). Also the favour for a new `semi-finish' grinding mill over a more energy efficient `finish' design was caused by concerns for the product quality.

6.4.6. Influence of government incentives.

It is difficult to evaluate the influence of energy (conservation) policy on the investments in the cement industry. The restricted natural gas supply policy led to the introduction of the first CHP plant in the cement industry. This was also supported by general investment grants and an energy bonus (Anon. 1981). Rising electricity prices and the same investment grants accompanied the introduction of a second CHP plant. Several energy conservation subsidies have been used in the observed period. In the cases of some subsidized investments (TIEB 1993, TIEB 1994), one might argue that the provided subsidies were not necessary for meeting the investment criteria of the cement industry.

Although not of importance for energy conservation measures before 1990, we shortly describe the agreement of the cement industry with the Ministry of Economic Affairs. In 1992, the Dutch cement sector has agreed to an energy conservation target of 20% in the year 2000, based on the specific energy consumption in the year 1989. This voluntary agreement (covenant) has been signed with the Ministry of Economic Affairs. Novem, a subsidiary of the Ministry of Economic Affairs takes care of the annual monitoring of the developments of the specific energy consumption. The reduction target for 1995 (-10%) was already reached in 1993 (Lanser 1994). Approximately 90% of this reduction was achieved with investments that had already been approved of before signing of the covenant. Although little pressure is constituted by the covenant, it has led to an improved understanding of the energy consumption (Lanser 1994).
Furthermore, the covenant may - like environmental standards - have the influence that part of the investments are not evaluated against the profitability criterion, because they are considered necessary investments. This was mentioned to have happened with the semi-finish grinding system (Gulikers 1994).

7. THE BRICK MANUFACTURING INDUSTRY

7.1. Introduction

In the brick manufacturing industry, common, face and pave bricks are manufactured. Over 1500 million bricks were produced in the Netherlands in 1990 (Van der Zwan and De Vries 1994). The brick manufacturing industry underwent a big rationalization process in the last twenty years. In this period 120 factories were closed, and employment came down from 11000 to the current figure of 2000 people (Van der Zwan and De Vries 1994). This changed the character of this branch, from labour intensive work to a modern branch of industry. In 1995, 5 large companies owned 32 factories, totalling 65% of the Dutch annual production. In 1990, the average price of common bricks was Dfl. 270 per 1000. The energy costs per 1000 bricks amounted to approximately Dfl. 40 (15%) (CBS 1990).

For the description of the brick production process we relied heavily on the extensive descriptions by Van der Zwan *et al.* (Van der Zwan and De Vries 1994, Van der Zwan *et al.* 1994). These papers are based on (among others) results from an inquiry that was set up to make an inventory of energy and environment related problems of the brick and roofing tiles industry. This inventory was used as a reference point study for the covenant that was signed with the Ministry of Economic Affairs in 1993. Like in the cement manufacturing industry, the agreement stipulates that the ceramics industry will reduce its specific energy consumption with 20% in the year 2000, relative to the year 1989 (EZ 1993).

7.2. Process Description

Bricks are manufactured from clay and loam. These raw materials are shaped, sometimes with the help of water and heat to raise the plasticity. After shaping, the bricks are dried in drying chambers, and subsequently fired in a kiln at approximately 1050°C (Van der Zwan and De Vries 1994). Pave bricks are fired at higher temperatures, but are not considered in this paper.

7.2.1. Shaping.

Shaping of the bricks may be carried out in continuous or discontinuous way. Before the actual shaping takes place the clay has to be wetted and heated to attain the required plasticity. This is done by adding water and/or steam to the clay. Shaping may be done by mechanically pushing the clay in a tray, or by cutting pieces from a clay-strand.

7.2.2. Drying of the bricks.

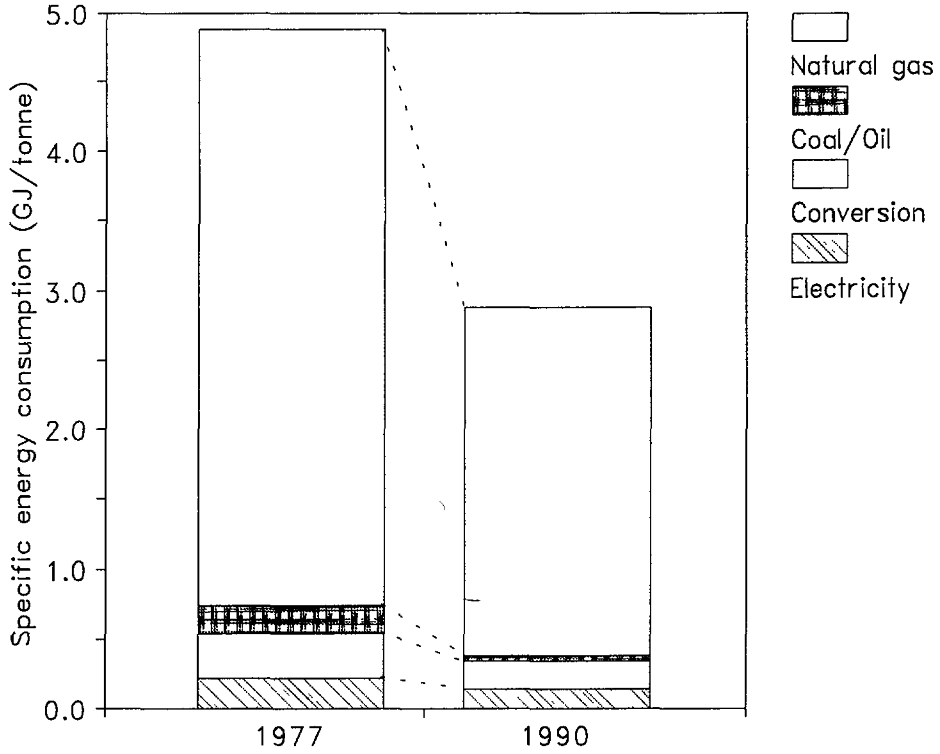
After shaping, the raw bricks contain between 20 and 30% water. Before firing, this water has to be removed in a drying process. Historically, drying used to take place in open air during the summer season. Presently, drying is performed in drying chambers or drying tunnels. For this process hot air is circulated with the help of fans. The heat is generally obtained from the cooling air from the kiln. If necessary, extra heat is generated with natural gas burners. The fans are the main consumers of electricity in the brick production process (Van der Zwan and De Vries 1994).

7.2.3. Firing of the bricks.

When the raw bricks are dry, they are introduced into the kiln. Bricks may be fired in either intermittent or continuous kilns. The latter type of kilns is the more modern type. The energy efficiency in continuously fired kilns is generally better because the kiln itself does not have to be heated for every batch. In continuous kilns we can make a difference between annular (or Hoffmann) kilns, chamber kilns and tunnel kilns. In the annular and chamber kilns, the bricks are stationary and the fire zone moves round the kiln. In the tunnel kiln, the fire is stationary and the bricks pass through on cars, gradually heating up and cooling down in the process.
After sintering, the bricks must be cooled quickly to remove the plasticity. This generally yields a large amount of hot air that is used for drying the raw bricks.

7.3. Development of the specific energy consumption

We calculated the specific energy consumption for the years 1977 and 1990. The production figures for common and pave bricks were taken from KNB (1986, 1991), and converted to tonnes by multiplying with the conversion factor of 1.73 tonne per 1000 bricks[3]. The energy consumption in 1977 is derived from Krekel *et al.* (1982). The data for 1990 are taken from CBS (1990). Between 1977 and 1990, the average primary energy consumption per ton of product decreased from 4.89 to 2.89 GJ (approximately -40%). This corresponds to an annual decrease rate of 4%. This development is depicted in figure 4.



The decrease rate in specific energy consumption of 4% per year is also mentioned by Van Duin (1981) for the period between 1977 and 1981. This author indicates that part of the decrease can be attributed to the closing of the most wasteful plants, and transfer of the production to modern plants.

7.4. Evaluation of the developments in energy efficiency in the brick industry

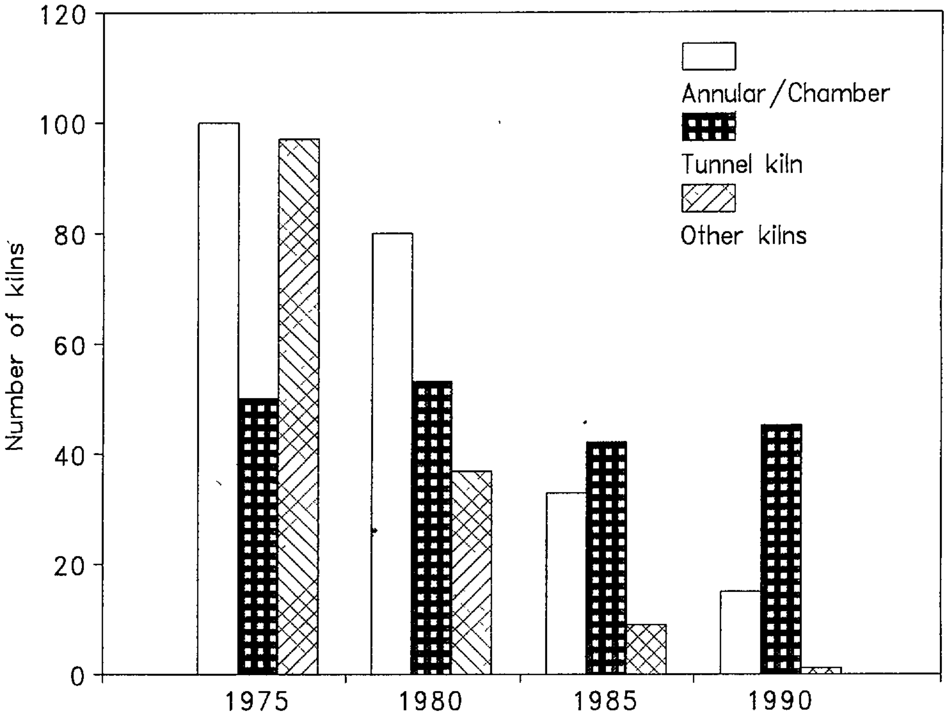
Reconstruction of the investments that led to the drastic decrease in specific energy consumption turned out to be very difficult. Many firms that produced bricks in the 1970's do not exist today. Data on some energy conservation options described in the literature are reported in table 3.

Table 3. Overview of some energy conservation projects in the brick manufacturing industry

Conservation measure	Type	Capacity (Mln WF)	Energy conservation Savings (%)	Energy conservation Savings (TJ)	Energy conservation Energy Carrier	Investment (Million Dfl.)	Pay-back period Energy (yr)	Pay-back period Total (yr)
Tunnel kiln for chamber kiln[a]	replacement	55	45	150	fuel	20	10-19	6-8
Optimization drying process[b]	retrofit	28→31	20	10	fuel	1	9	?[c]
Kiln cooling air for drying[d]	retrofit	50	20	60	fuel	0.8	1	1
Heat recovery from kiln flue gas[e]	retrofit	?	10-13	15	fuel	?	2-3	2-3
Impulse burners[f]	retro/repl.	?	?	6	f/e	0.3	8	?[g]
Insulated (LTM) cars for tunnel kiln[h]	replacement	60	8	18	fuel	0.2	1.5	1.5[i]
CHP installation[j]	retrofit	50	20	46	f/e	2.5	4	4

(a) Figures based on (Krekel *et al.* 1982, Anon. 1984, Brugman 1995). The range in the PBP is related to the variations in gas prices between 1980 and 1990. For the total PBP we assumed a reduction in labour costs of 20 people (Brugman 1995), and Dfl 80,000 savings per person; (b) This investment is described in (Novem 1991b). Although a fuel conservation was achieved, the overall result was less than expected due to an increase in electricity consumption. The actual PBP after project evaluation is reported here, (c) The effect of an increasing capacity could not be expressed in financial terms, (d) Investment described in (Neom/Sven 1985) A fan that was installed, led to an electricity consumption increase of 5.5 kWh/1000 bricks This is accounted for in the PBP; (e) Based on (Weydema 1985); (f) Investment described in (Neom/Sven 1987) In the project natural gas as well as electricity savings were achieved The PBP is based on the savings on natural gas because the electricity savings were not quantified; (g) Other benefits could not be quantified; (h) The investment in insulated `low thermal mass' cars is described in (Novem 1991a). It concerns a replacement and investment costs relate to the extra costs as compared to conventional cars; (i) Although the maintenance costs are lower for these cars than for conventional cars, this could not be expressed in financial terms, (j) The data are modelled on the basis of an average modern brick factory with a capacity of 50 million bricks per year, described in (Van der Zwan *et al* 1994) The extra heat needed for the dryer is generated with a 2.6 MW gasturbine-generator set Investment costs are estimated at 3 million Dfl., and the electricity generating efficiency is taken to be 35% With the average 1990 gas and electricity prices for brick factories (0 228 Dfl/m^3 and 0.127 Dfl/kWh) (CBS 1991), we calculated a PBP of 4 year.

A large part of the decrease in SEC between 1977 and 1990 may be explained by the replacement of kilns. In 1978, less than 40% of the production capacity consisted of tunnel kilns, but all new kilns since then were expected to be modern tunnel kilns (Krekel *et al.* 1982). In 1990 the percentage of tunnel kilns in the total production had increased to over 75% (Huizinga *et al.* 1992). The replacement of kilns in the Dutch brick manufacturing industry is depicted in figure 5.



From figure 5 we can see that the number of kilns decreased fast, and that the share of tunnel kilns increased. The decrease in the number of kilns exceeds the decrease in the number of plants; between 1970 and 1990 approximately 100 production units were closed (Van der Zwan and De Vries 1994). This indicates that the average kiln capacity has increased in the past decades, which is confirmed by data in Van der Zwan *et al.* (1994).

7.4.1. Developments in the specific energy consumption.

The specific energy consumption in the brick manufacturing industry decreased between 1977 and 1990, with an average rate of 4%. This large decrease may partly be attributed to the fact that the situation in 1977 was very energy inefficient. It is estimated that (in the last 15 years) replacements of kilns and drying equipment, and the closing of obsolete plants have contributed for approximately 80% to the energy efficiency increase in the brick manufacturing industry (Van Mosseveld 1995). The closing of old plants may also be regarded as replacements because the production capacity was taken over by other firms. The remaining 20% energy efficiency improvement is achieved with good housekeeping measures and add-on investments.

The many replacements of kilns and dryers did not lead to an optimal energetic situation in most plants because the investments in kiln and dryer are usually separated in time. For add-on investments the brick industry uses a pay-back criterion in the order of 3 years (Drenthen 1995, Van Mosseveld 1995). Many investments serve multiple purposes. The main purposes are increasing production capacity, decreasing labour and other production costs, and complying with environmental regulations. Measured in financial terms, the reduction of labour costs has been the main incentive for the introduction of modern large-scale tunnel kilns.

Like in the cement industry, the equipment has very long lifetimes. Postponement of replacements is possible until these replacements become very attractive in an economic sense, or other requirements (e.g. environmental) can be incorporated in the new equipment.

Accelerated replacement of equipment has occurred when energy prices were high, and when increasing production capacity was necessary. According to Drenthen (1995), the high energy prices in the period 1980-1985 led to increased investments in energy conservation, including complete replacements of kilns.
Between 1980 and 1988, an energy bonus was available in the Investment Account Act. This meant that 10% of the investments in energy conservation (20% in 1982-1983) could be deducted from taxes. Only investments directed at energy conservation could apply for the subsidy. From data on these subsidies (Senter 1994b), we derived that in two years with high energy prices (1984-1985) approximately 20-30% of the total investments in the brick industry related to energy efficiency improvement. In the years 1986-1987, the energy prices collapsed, and the investments in energy efficiency improvement made up less than 5% of the total investments.

7.4.2. Barriers: competition and information exchange.

The Dutch demand for bricks is almost entirely produced in the Netherlands. The export of bricks amounted to 14% in 1978 (Weydema 1985), and 23% of the production in 1991 (KNB 1991). The import was less than 5% of the total production in 1991 (KNB 1991). Competition exists mainly within the Dutch market for bricks. Brick manufacturing firms are careful with giving away knowledge to competing firms (Drenthen 1995).
Suppliers of equipment are important sources of information (Drenthen 1995). Furthermore, two institutions supply a large amount of information to the brick manufacturing industry. The first is the technical centre for the ceramic industry (TCKI), which supports their members with advice, studies, and monitoring activities. The second party is TNO-TPD, a joint research institute of the Netherlands organization for applied scientific research and the Technical university Delft. In this institute R&D research (including energy aspects) is carried out for the ceramic industry.

7.4.3. Barriers: investment and profitability criterion.

On average pay-back periods of 3 year are considered profitable in the brick manufacturing industry (Drenthen 1995, Van Mosseveld 1995). One representative of the industry (Drenthen 1995) communicated that a more sophisticated profitability criterion than the PBP was used in his company. In this company (with 9 plants in The Netherlands), investment proposals were approved of by the central management staff.
There seems to be a distinction between two types of replacement investments in the brick industry. The first type consists of replacements that are necessary to warrant production continuity, the second type consists of replacement of old but still functioning equipment. For investments of the first type little dispute is necessary. However, for investments of the second type a profitability criterion is used. Longer pay-back periods are accepted for replacement investments of the second type than for add-on investments. For these replacements PBP's in the order of 10 years are considered acceptable (Van Mosseveld 1995).

7.4.4. Other barriers.

The brick industry produces a large variety of bricks, with different surfaces and colours. These variations are made to satisfy the market demand, and product development is one of the means for market expansion of firms. These variations also have an impact on the specific energy consumption. For instance the specific energy consumption for yellow bricks is generally higher than for red bricks because of the lime content in yellow bricks (Drenthen 1995). For specific markets (e.g. restoration) bricks are produced with energy-inefficient methods (e.g. firing with coal in small batches) (Uittenbosch 1994). The higher energy costs of these brick variations are generally compensated by the higher value added of these bricks.

7.4.5. Influence of government incentives.

It is difficult to evaluate the influence of energy policy on the developments in the brick manufacturing industry. The energy bonus in the Investment Account Act may have accelerated investments in energy conservation, but the influence of energy prices seems larger. Subsidies for demonstration projects have been given for projects with already low PBP's of 1-2 years (Neom/Sven 1985, Novem 1991a) or to factories that were closed shortly afterwards (Novem 1991c, Drenthen 1995).

Although not important for explaining the developments between 1977 and 1990, some policy actions that may exert influence on the energy efficiency are described.

The brick manufacturing industry has agreed to reduce its (specific) energy consumption by 20% between 1989 and 2000 (EZ 1993). In the covenant a number of energy conservation measures are described. Together these measures are believed to reduce the specific energy consumption with 15-24%, of which 15-20% can be realized on the basis of autonomous developments with knowledge and techniques that are already available, or will be available before long (EZ 1993). It is expected that the brick manufacturing sector will achieve its energy reduction goal with some efforts, but without many problems (Uittenbosch 1994).

The introduction of environmental care systems ('Milieuzorgsysteem' MZS) is going to be enforced in the brick manufacturing industry (Drenthen 1995). Because of this obligatory action, factories are busy with making an inventory and mass balances for their production process. The MZS must also include an annual report of the energy consumption. According to Drenthen (1995) these actions lead to an increased insight in the energy consumption related to the sub-processes and production conditions. Also equipment (e.g. motors) with too large capacities are encountered during the inventories. The improved insight may, in due time, lead to energy conservation measures.

The brick manufacturers are being confronted with policies to curb emissions of dust, NO_x, sulphur trioxide and fluor (KNB 1991). The fluor emissions are an important problem in the production of bricks; the fluor is released from the clay during the process, in the form of hydrofluoric acid (Van der Zwan 1995). Because the government aims at reducing these emissions with 80-90%, flue gas purifying equipment will be introduced in the brick industry (Drenthen 1995). Studies have indicated the possibility to include flue gas heat recovery in the purifying equipment, and save a substantial amount of energy (KNB 1991). Studies are also being performed to find process-integrated emission abatement options. The prospects are that with a new kiln design, both fluor emissions and energy consumption could be reduced (Van der Zwan 1995).

8. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

We are aware of the fact that the building materials industries, with their saturated markets are not representative for the manufacturing industry sector as a whole. Despite this restriction, we think that part of the findings may be extrapolated to other energy intensive branches of industry.

In the two subsectors within the building materials industry that we considered, the specific primary energy consumption decreased with 1% and 4% per year respectively (between 1977 and the early 1990's). These changes in specific energy consumption can to a large extent be explained by the energy efficiency measures that were distinguished for both subsectors. In spite of this considerable difference in efficiency improvement rate, the investment behaviour with respect to energy consumption has much in common in both subsectors.

By far the major efficiency improvements are attained by the replacement of old equipment. The reasons for such replacements are excesses or shortages of capacity, reduction of labour costs, and simply because the replaced equipment was worn out. Reduction of the specific energy consumption is only a by-product of these replacement investments. In addition to such replacements, also add-on (retrofit) investments have been carried out; mainly in the period of high energy prices (1980-1985). Also for these investments, other objectives like reduction of labour costs played a dominant role.

With respect to the barriers to energy conservation we found that lack of information of efficient processes played a minor role in preventing measures from being taken. On the other hand, the insight in the energy consumption at the (unit) process level may be improved. This may be derived from the results of inventories of energy consumption at the firm level. These inventories are currently performed in relation to the agreements with the government to reduce energy consumption. These inventories resulted in increased knowledge of the own energy consumption.

Economic barriers, like (too) stringent investment criteria (e.g. pay-back periods of less than three years), did not seem to play an important role in preventing measures from being implemented. No difference was observed in the evaluation of energy conservation investments, and investments for other purposes. Barriers that were observed in the building materials subsectors are:

- the long lifetime of equipment in this sector (typically 30-50 years);
- the fear for decreased product quality;
- doubts about the technical feasibility of measures.

The effect of government incentives up to now seems low. The investment subsidies provided in the 1980's seem sometimes to have suffered from a free rider effect. The covenants that were agreed upon in recent years are filled for a considerable part with measures already planned by the respective industries. However, the covenants may speed up investments by bringing energy conservation under closer management attention. The representatives in the sector were well aware of the agreement and seemed confident about reaching the goal. Environmental regulations with other purposes than energy conservation are able to induce developments that lead to improved energy efficiency.

9. ACKNOWLEDGEMENTS

The research project described in this paper was financially sponsored by the National Programme on Global Air Pollution and Climate Change (NOP-MLK). This support is thankfully acknowledged. The authors also like to thank all persons who were co-operative to answer all our questions.

10. ENDNOTES

1. Dfl = Dutch Guilder; 1 ECU (European currency unit) = 2.25 Dfl
2. These changes in specific energy consumption were calculated as follows: the production figures for bricks, cement and glass (in tonnes per year) were multiplied with their specific energy consumption in a base-year, and then summed. The ratio of the thus generated aggregate (energy-weighted) production figure and the energy consumption was taken as a indicator of specific fuel/electricity consumption (cf. Farla *et al.*, 1994).
3. The Dutch standard brick size is called `Waalformaat' (WF). The production reported in numbers of bricks may be converted to tonnes of brick by using the average weight of 1.73 kg per brick WF (KNB 1986).

Table 2. Overview of energy conservation projects in the cement industry

Conservation measure		Energy conservation				Pay-back period	
		Savings (%)	Potential (PJ_p)[a]	Energy carrier	Investment (Million Dfl.)	Energy (yr)	Total[b] (yr)
Clinker production							
Introduction of dry process	replacement	>20[c]	0.6[d]	fuel	150-200[e]	>25	?[f]
Feed preheater[g]	retrofit	2.5	0.2	fuel	32	>25[h]	?[f]
Advanced process control[i]	retrofit	3	0.1	fuel	1	4	1
Slag addition[j]	oper. change	3	0.1	fuel	n/a	n/a	n/a
New kiln	replacement	13[k]	0.5[k]	fuel	200[l]	>25	?[f]
Finish grinding							
High efficiency classifier	replacement	18[m]	0.3	elec.	3[n]	3	3[o]
Roller press (semi-finish)	replacement	30[p]	0.5[q]	elec.	68[r]	>25[r]	>10[r]
Roller press (finish)	replacement	45[s]	0.7	elec.	10[t]	3-10	?[f]
Increase milling additives	oper. change	13[u]	0.2[v]	elec.	n/a	n/a	n/a
Other measures							
Management info system[w]	retrofit	?	?	f/e	?	n/a	n/a
Slag drying with CHP	retrofit	25[x]	0.2[y]	elec.	25[z]	3	3

(a) Electricity is converted to demand on primary energy carriers by multiplying with 2.5; (b) With total Pay-back period we mean the PBP when taking also quantifiable non-energy benefits into account; (c) Derived from (Holderbank 1993); (d) Based on a production capacity of 1000 ktonne clinker, assuming the shares wet process/dry process = 60/40, and assuming a SEC of 5 GJ per tonne clinker for the wet process, and 4 GJ/tonne for the dry process in 1977; (e) Estimate from (Krekel *et al.* 1982); (f) Non-energy benefits unknown; (g) Data from (Dassen 1995); (h) Calculated with a fuel price of 3 Dfl/GJ; (i) Data on this measure were derived from (Juijn 1994) and (TIEB 1994), (j) Data from (Dassen 1994, Lanser 1994); (k) Figures calculated for a 1000 ktonne/yr capacity, with present SEC of 3.6 GJ/tonne clinker (Dassen 1994), and an achievable SEC of 3.1 GJ/tonne (Holderbank 1993, Anon. 1994a, Anon. 1994b); (l) Estimate by (Gulikers 1994); (m) Derived from (TIEB 1993, Gulikers 1994); (n) Investment figure from (TIEB 1993), for a capacity of approx. 600 kton/yr; (o) Lower PBP possible, because of lower share of clinker needed for blast furnace cement (TIEB 1993); (p) Estimated electricity savings based on (Gulikers 1994), (q) Based on the electricity requirement for milling of 200 GWh, derived from (Baumann 1994, Gulikers 1994, Maaskant 1994); (r) The investment figure of 68 Mln Dfl. relates to one specific investment project. Annual savings are estimated to amount to 2 Mln Dfl. for electricity, 2.5 Mln Dfl for labour costs, and 1.5 Mln Dfl. for savings on maintenance costs (Gulikers 1994), (s) Derived from (Gulikers 1994); (t) Estimate on the basis of (Holderbank 1993, Gulikers 1994); (u) Data from (Maaskant 1994); (v) The savings are extrapolated to the total electricity consumption for milling; (w) No estimates available on potential energy savings and investment costs, (x) Energy savings estimated on the basis of (Anon. 1981, Krachtwerktuigen 1991); (y) Potential calculated for 1400 ktonnes of slag (1992), and a heat consumption of 0.7 GJ/tonne of wet slag (Van Duin 1981, Van Dijck 1991); (z) Estimated for a total capacity of 19 MW_e, on the basis of actual investment figures for a 3.2 MW plant (Anon. 1981), and a 12 MW plant (Klein 1994); (A) 80% of the CHP capacity for slag drying is implemented, based on the blast furnace production figures for 1992, (B) In 1994, a 3.2 MW_e CHP plant (1981) was replaced with a 4.8 MW_e CHP plant (Baumann 1994, Senter 1994a).

Allen, T.J, D.B. Hyman, and D.L. Pinckney, 1983: *Transferring Technology to the Small Manufacturing Firm: A Study of Technology Transfer in Three Countries*, Research Policy, **12**, p. 199-211.

Anon., 1981: *Warmte-Krachtcentrale ROBUR bv (Combined Heat and Power Plant ROBUR bv)*, Polytechnisch Tijdschrift/Werktuigbouw, **36** (8), p. 399.

Anon., 1984: *Uitgelicht (Spotlight)*, Energiebesparing (12), p. 11.

Anon., 1994a: *Cement Plant Modernization in Central Europe*, World Cement, (November 1994), p. 35-38.

Anon., 1994b: *Die Zementindustrie Taiwans - Rückblick und gegenwartiger Stand (The Cement Industry in Taiwan - History and Current Situation)*, Zement-Kalk-Gips, **47** (1), p. 47-50.

Baumann, J.R., 1994: *Personal Communication*, Cementfabriek Rozenburg (ROBUR bv), Rozenburg, The Netherlands.

Boyd, G., J.F. McDonald, M. Ross, and D.A. Hanson, 1987: *Separating the Changing Composition of U.S. Manufacturing Production from Energy Efficiency Improvements: A Divisia Index Approach*, The Energy Journal, **8** (2), p. 77-96.

Brugman, 1995: *Personal Communication*, Boral Nedusa Baksteen bv, Erlecom, The Netherlands.

Burke, D.J., 1994: *TAPPI Survey of Energy Consumption*, TAPPI Journal, **77** (9), p. 59-63.

CBS, 1980-1990: *Maandstatistiek van de Industrie (Monthly Statistics of Industrial Production)*, Vol. 1980-1990, Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.

CBS, 1980-1992: *De Nederlandse Energiehuishouding; Jaarcijfers (Energy-Supply in the Netherlands; Annual Figures)*, Vol. 1980-1992, Netherlands Central Bureau of Statistics, Voorburg, The Netherlands.

CBS, 1985/1988/1993: *Maandschrift (Monthly Bulletin)*, Vol. 1985/1988/1993, Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.

CBS, 1990: *Produktiestatistieken Industrie, Baksteenindustrie 1990 (Industrial Production Statistics, Manufacture of Bricks 1990)*, Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.

CBS, 1991: *De Nederlandse Energiehuishouding - Jaarcijfers 1990 (Energy Supply in the Netherlands - Annual Figures 1990)*, Centraal Bureau voor de Statistiek, Voorburg, The Netherlands.

CBS, 1993: *De Nederlandse Energiehuishouding - Jaarcijfers 1991 (Energy Supply in the Netherlands - Annual Figures 1991)*, Vol. 2, Centraal Bureau voor de Statistiek, Voorburg, The Netherlands.

Dassen, R., 1994: *Personal Communication*, ENCI bv, Maastricht, The Netherlands.

Dassen, R., 1995: *Written Communication*, ENCI bv, Maastricht, The Netherlands.

De Beer, J.G., M.T. Van Wees, E. Worrell, and K. Blok, 1994: *ICARUS-3: The Potential of Energy Efficiency Improvement in the Netherlands up to 2000 and 2015,* Utrecht University, Dept. of Science, Technology and Society, Report nr. 94013, Utrecht, The Netherlands.

Drenthen, M., 1995: *Personal Communication.* 1995, TERCA (formerly: Teewen Koramic), Swalmen, The Netherlands.

ENCI, 1977: *Written Communication*, Maastricht, The Netherlands.

EZ, 1993: *Meerjarenafspraak tussen de Grofkeramische Industrie en de Minister van Economische Zaken over Verbetering van de Energie-efficiency (Long-term Agreement between the Ceramics Industry and the Ministry of Economic Affairs Concerning Energy Efficiency Improvement),* Ministry of Economic Affairs, Zoetermeer, The Netherlands.

Farla, J., R. Cuelenaere, and K. Blok, 1994: *Energy Efficiency and Structural Change in The Netherlands, 1980-1990,* Dept. of Science, Technology and Society, Report nr. 94007, Utrecht, The Netherlands.

Fog, M.H. and K.L. Nadkarni, 1983: *Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing countries*, Industry and Finance, Vol. 2, The World Bank, Washington, D.C., USA.

Gillissen, M. and H. Opschoor, 1994: *Energy Conservation and Investment Behaviour: an Empirical Analysis of Influential Factors and Attitudes,* FEWEC, Free University, Report nr. RM 1994-31, Amsterdam, The Netherlands.

Gruber, E. and M. Brand, 1991: *Promoting Energy Conservation in Small and Medium-Sized Companies,* Energy Policy, **19** (3), p. 279-287.

Gulikers, 1994: *Personal communication*, ENCI bv, Maastricht, The Netherlands.

Holderbank, 1993: *Present and Future Use of Energy in the Cement and Concrete Industries in Canada,* Holderbank Consulting Ltd., Efficiency and Alternative Energy Technology Branch, CANMET, Ottawa, Ontario, Canada.

Huizinga, K., J.J. Verburgh, and A.J.C.M. Matthijsen, 1992: *Grofkeramische Industrie (Coarse Ceramics Industry),* RIVM, Report nr. RIVM 736301112, Bilthoven, The Netherlands.

Jacobs, M., 1994: *Peronal Communication.* 1994, ENCI nv, 's-Hertogenbosch, The Netherlands.

Jenne, C.A. and R.K. Cattell, 1983: *Structural Change and Energy Efficiency in Industry,* Energy Economics, (April 1983), p. 114-123.

Juijn, P., 1994: *Vage logica leidt tot concrete energiebesparing (Fuzzy Logic Leads to Real Energy Conservation),* Energie- en Milieuspectrum, (9), p. 22-23.

Klein, 1994: *Personal Communication*, CEMIJ bv, Velsen, The Netherlands.

KNB, 1986: *Jaarverslag KNB 1986 (Annual Report 1986),* Koninklijk Verbond van Nederlandse Baksteenfabrikanten, De Steeg, The Netherlands.

KNB, 1991: *Jaarverslag KNB 1991 (Annual Report 1991),* Koninklijk Verbond van Nederlandse Baksteenfabrikanten, De Steeg, The Netherlands.

KNB, 1993: *Jaarverslag KNB 1993 (Annual Report 1993),* Koninklijk Verbond van Nederlandse Baksteenfabrikanten, De Steeg, The Netherlands.

Krachtwerktuigen, 1991: *Referentielijst van in Nederland in Bedrijf Zijnde Warmte/Kracht-installaties op Basis van Gasturbines (Reference List of Combined Heat and Power Installations Currently in Use in the Netherlands),* 4th ed., ed. A. Zwennes, Amersfoort, The Netherlands.

Krekel, N.R.A., E.P. Brouwer, S.G.K Ouendag, and A.A. Melman, 1982: *Energie en Economie, Produktbijlagen (Energy and Environment, Product Appendices),* Vol. III, COB/SER, The Hague, The Netherlands.

Lanser, P., 1994: *Personal Communication*, VNC, 's-Hertogenbosch, The Netherlands.

Maaskant, B., 1994: *Personal Communication*, Cementfabriek IJmuiden (CEMIJ bv), Velsen, The Netherlands.

Neom/Sven, 1985: *Demonstratieprojecten Energiebesparing: Energiebesparing bij een Steenfabriek (Demonstration Projects Energy Conservation: Energy Conservation in a Brick Manufacturing Plant),* Neom/Sven, Report nr. 37, Sittard/Apeldoorn, The Netherlands.

Neom/Sven, 1987: *Demonstratieprojecten Energiebesparing: Impulsbranders voor Tunneloven (Demonstration Projects Energy Conservation: Impulse Burners on a Tunnel Kiln),* Neom/Sven, Report nr. 274, Sittard/Apeldoorn, The Netherlands.

Novem, 1991a: *Demonstratieprojecten Energiebesparing: Geïsoleerde Ovenwagens voor Baksteentunnelovens (Demonstration Projects Energy Conservation: Insulated Cars for Tunnel Kilns),* Novem, Report nr. 306, Utrecht, The Netherlands.

Novem, 1991b: *Demonstratieprojecten Energiebesparing: Optimalisering van Droogproces in Steenfabriek (Demonstration Projects Energy Conservation: Optimization of Drying Process in Brick Manufacturing Plant),* Novem, Report nr. 350, Utrecht, The Netherlands.

Novem, 1991c: *Demonstratieprojecten Energiebesparing: Stortgasbenutting in Tunneloven (Demonstration Projects Energy Conservation: The Use of Garbage Dump Gas in a Tunnel Kiln),* Novem, Report nr. 236, Utrecht, The Netherlands.

Ross, M., *1986: Capital Budgeting Practices of Twelve Large Manufacturers,* Financial Management, **Winter**, p. 15-22.

Sassone, P.G. and M.V. Martucci, 1984: *Industrial Energy Conservation: The Reasons behind the Decisions,* Energy, **9** (5), p. 427-437.

Schipper, L., R.B. Meyers, R. Howarth, and R. Steiner, 1992: *Energy Efficiency and Human Activity: Past Trends, Future Prospects*, Cambridge University Press, Cambridge USA.

Senter, 1994a: *Jaarverslag WKK 1993 (Annual Report CHP 1993),* Senter, Zwolle, The Netherlands.

Senter, 1994b: *Written Communication on the Energy Bonus in the Investment Account Act*, Zwolle, The Netherlands.

Smit, J.R.K., 1993: *Produktie van Cement (Production of Cement),* RIVM, Report nr. RIVM 736301136, Bilthoven, The Netherlands.

TIEB, 1993: *Vervanging afscheiders in cementmaalsysteem (Replacement of a classifier in a cement mill),* Novem, Report nr. 39620/0057, Apeldoorn.

TIEB, 1994: *Aanschaf en Implementatie van Fuzzy Logic Besturingssysteem en Infrarood CEM-scanner voor Oven 8 (Acquisition and Implementation of a Fuzzy Logic Control System and Infrared CEM-scanner for Kiln 8),* Novem, Report nr. 39820/0069, Apeldoorn.

U.S. Congress, Office of Technology Assessment, 1993: *Industrial Energy Efficiency*, U.S. Government Printing Office, Washington, D.C., U.S.A.

Uittenbosch, M., 1994: *Personal Communication*, Koninklijk Verbond van Nederlandse Baksteenfabrikanten, De Steeg, The Netherlands.

Van der Zwan, J., 1995: *Personal Communication*, TNO-TPD, Dept. of Ceramics, Eindhoven, The Netherlands.

Van der Zwan, J. and A.H. De Vries, 1994: *De Metselbaksteen Industrie in Nederland (Brick Industry in the Netherlands),* Klei/Glas/Keramiek, **15** (9), p. 206-209.

Van der Zwan, J., A.H. De Vries, and R. Van der Stel, 1994: *De Metselbaksteen Industrie in Nederland, De Energie- en Milieusituatie (Brick Industry in the Netherlands, Energy and Environment),* Klei/Glas/Keramiek, **15** (11), p. 283-286,293.

Van Dijck, F.W.H.M., 1991: *CO_2 Emissie en Energieverbruik bij de Produktie van Cement (CO_2 Emissions and Energy Consumption in the Production of Cement),* PBI, Report nr. R 90.098, Sittard, The Netherlands.

Van Duin, R., 1981: *Verbruiksontwikkelingen in de Bouwmaterialensector (Developments in the Consumption in the Building Materials Sector),* B&G, Report nr. 81-2, Rotterdam, The Netherlands.

Van Mosseveld, K., 1995: *Personal Communication,* Technical Centre for the Ceramic Industry TCKI, De Steeg, The Netherlands.

Velthuijsen, J.W., 1993: *Incentives for Investment in Energy Efficiency: An Econometric Evaluation and Policy Implications,* Environmental and Resource Economics, **3**, p. 23-39.

Weydema, A., 1985: *Minder Energie Nodig voor Drogen en Bakken van Stenen (Less Energy Needed for Drying and Firing of Bricks),* Energiebeheer, **1985** (5), p. 6-11.