NEUERE BERECHNUNGEN ZUM PRIMÄRENERGIEINHALT VON GASBETON

MORE RECENT CALCULATIONS OF THE PRIMARY ENERGY COSTS OF AUTOCLAVED AERATED CONCRETE

E.FREY, Head of Central Laboratory; D.BRIESEMANN, President;
Hebel Emmering GmbH & Co., D-8080 Emmering, Federal Republic of Germany

KURZFASSUNG

Nach der Methode der Prozeßkettenanalyse wird der gesamte Primärenergieverbrauch zur Gasbetonherstellung untersucht. Es werden die Daten von sieben Werken eines Gasbetonherstellers von 1980 bis 1983 ausgewertet. Bei der Dampfhärtung konnten in allen Werken erhebliche Energieeinsparungen durch bessere Ausnutzung der Dampfenergie erzielt werden. Für 1983 wurde ein durchschnittlicher Gesamtenergieverbrauch von 1465 MJ pro Kubikmeter Gasbeton der mittleren Rohdichte 505 kg/m³ erhalten. Davon entfielen 60% auf die Rohstoffherstellung, 5% auf den Rohstofftransport und 35% auf die Produktion im Gasbetonwerk.

ABSTRACT

Methods of process chain analysis are employed for an investigation of the total primary energy consumed in the production of autoclaved aerated concrete (AAC). The data compiled in the production in seven factories of an AAC manufacturer from 1980 to 1983 are evaluated. In all factories, the energy required for autoclaving has been reduced by an improved utilization of the steam energy. In 1983, the average total energy consumption amounted to 1465 MJ per cubic meter of AAC having an average bulk density of 505 kg/m³. 60% of that energy consumption were used to produce the raw materials, 5% to transport the raw materials, and 35% to produce AAC in the factory.

1. INTRODUCTION

As the need to save energy is becoming more apparent, some scientific papers (1-4) concerned with the primary energy costs (PEC) of building materials had been published in recent years. The main question is whether the primary energy consumed to produce a building material has a reasonable relation to the room-heating energy which can be saved if structures are compared which have the same heat transmission coefficient (k value).

For the conditions in the Federal Republic of Germany, Marmé (3) has covered all imporant building materials and has furnished data which can well be compared and are sufficiently accurate. The present paper reports the results of an investigation of the energy consumed in the production of AAC blocks. The procedure adopted for that investigation was similar to that of Marmé. The energy figures were compiled from seven factories of a West German AAC manufacturer and were evaluated for the four years from 1980 to 1983.

2. METHODS AND CONDITIONS

The energy consumption was determined by process chain analysis involving an addition of the primary energy consumed in each production stage. Figure 1 is a schematic representation of the process chain for producing autoclaved aerated concrete.

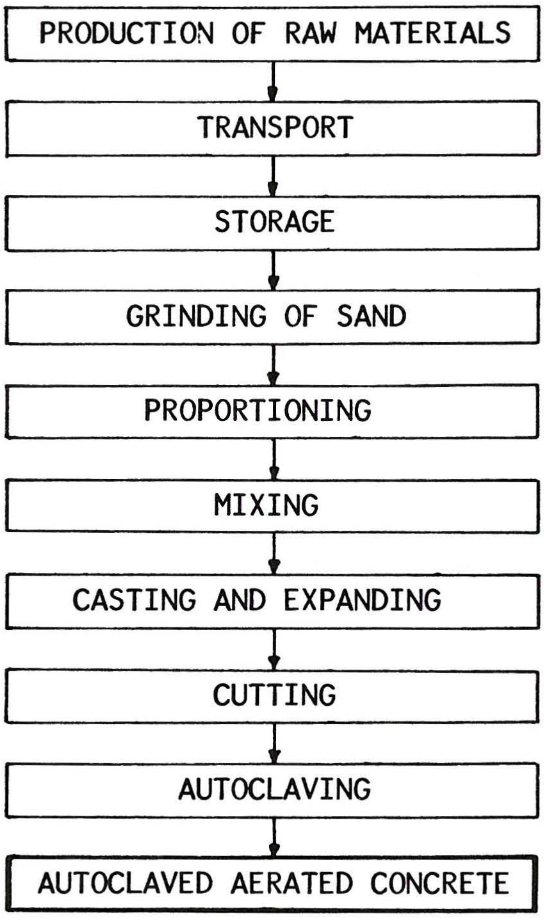

Fig.1 Process Chain of Production of Autoclaved Aerated Concrete

The energy required to produce autoclaved aerated concrete can be divided into three parts:

- Indirect energy required to produce the raw materials contained in AAC and to produce the auxiliary materials consumed

- Indirect energy required to transport the raw materials to the factory

- Direct energy consumed for the actual production in the factory.

Additional parts, such as the proportional consumption of energy for the construction of the production plants and machinery or for the production and transport of primary and secondary energies (gas, oil, coal) have not been taken into account. The following efficiencies stated by Marmé (4) were used in the calculation of the PEC of the secondary energies employed:

- Natural gas: 100%
- Fuel oil, butane gas: 92,5 % (refinery efficiency)
- Electric power: 39% (conversion efficiency)

The colorific values and the PEC figures of the energy carriers used in the production of AAC have been compiled in Table 1.

Energy carrier	Calorific value		Primary energy costs (PEC)	
	MJ	kWh	MJ	kWh
1 kg Fuel oil, light	42.71	11.86	46.17	12.82
1 kg Fuel oil, heavy	41.03	11.40	44.36	12.32
1 m^3 Natural gas *	~37,8	~10,5	~37.8	~10.5
1 kg Butane gas	45.74	12.71	49.45	13.74
1 kWh Electric power	3.6	1.00	9.23	2.56

* The exact calorific value of natural gas will be stated by the supplier.

Table 1 Primary Energy Costs of the Secondary Energies Used in the Production of AAC - Dates as furnished by Marmé (3)

The transport by lorries as the only means used to transport the raw materials for AAC was taken into account with 2.85 MJ/(txkm) (t = metric ton of 1000 kg), in accordance with Marmé.

3. PRIMARY ENERGY COSTS OF THE RAW AND AUXILIARY MATERIALS

Raw materials for AAC are quartz sand, lime, hydraulic cement, aluminum and water. Auxiliary materials used in the production are the grinding elements used to grind the sand and the mould oil used as a release agent to facilitate the removal of the green aerated concrete from the casting moulds.

The PEC figures for said materials have been compiled in Table 2, also as furnished by Marmé, and are applicable only to the conditions in the Federal Republic of Germany.

Raw material		PEC MJ
1 t	Sand	15.1
1 t	Portland cement	4046.0
1 t	Quicklime	5536.0
1 kg	Aluminum	261.0
1 kg	Mould oil	44.3
1 kg	Grinding elements	~40.0
1 m³	Water	2.7

Table 2 Primary Energy Costs of the Raw and Auxiliary Materials Used in the Production of AAC - Data as furnished by Marmé (3)

It is interesting to note that Portland cement has lower PEC than quicklime so that a formula for autoclaved aerated concrete containing a binder which consists mainly of hydraulic cement will require less energy than a highlime formula. All factories covered by the present investigation used high-cement formulae. Mould oil was considered to have the same PEC as light fuel oil. The PEC value for the grinding elements made of a special alloy was estimated. The recovery of water has such a low energy requirement that it has been neglected in the present investigation.

To calculate the PEC of the raw materials contained in one cubic metre of AAC, the PEC values of the several components sand, hydraulic cement, lime and aluminum, were proportionally added. This method was also adopted for the auxiliary materials consumed per cubic metre of AAC. The average bulk density of the dry concrete must also be stated if PEC figures are stated per unit of volume and was calculated as the total of the average weights of raw materials per cubic metre of AAC with an addition of 10 wt.% crystal water. As an example for 1983, the PEC values of the raw and auxiliary materials and the average bulk densities for seven AAC factories have been compiled in Table 3, in which all figures relate to the manufacture of blocks whereas prefabricated elements provided with steel reinforcements have not been covered.

Factory	A	B	C	D	E	F	G	Average
				MJ/m³				
Raw Materials	872	953	903	896	721	701	788	833
Auxiliary materials	32	36	51	34	58	46	43	43
Total	904	989	954	930	779	747	831	876
bulk density kg/m³	493	542	465	500	553	504	490	507

Table 3 Primary Energy Costs of the Raw and Auxiliary Materials Used in Seven Factories in 1983 to Produce One Cubic Metre of AAC

On the average of the seven factories, the PEC of the raw materials amounted in 1983 to 833 MJ/m³. Of that value, hydraulic cement accounted for 52%, lime for 33%, aluminum for 14% (!) and sand only for 0,5%. The auxiliary materials accounted for 43 MJ/m³, on an average, and one-third of that figure was due to the consumption of mould oil whereas two-thirds were due to the consumption of grinding elements. The average bulk density of all bricks which had been produced amounted to about 507 kg/m³. This shows that previously published statements of 700 kg/m³ for AAC are obsolete or never reflected actual conditions. The differences between the bulk densities are due to the fact that different density classes were made in different proportions in the several factories. The variation of the raw materials energy costs between 700 and 950 MJ/m³ does not correlate with the bulk densities but depends almost exclusively on the different binder contents called for by the formulae. In dependence on the quality of the sand which is available and on the time for which the green aerated concrete is stored until it is cut, more or less binder is required in the mix.

It is apparent from Table 4 that there has been almost no change of the energy costs of the raw materials contained in the autoclaved aerated concrete from 1980 to 1983 because the formulae and the densities of the blocks produced remained almost the same.

	Average values in MJ/m³					
	1980	1981	1982	1983	Average	%
Raw materials	821	821	814	833	822	95
Auxiliary materials	45	44	40	43	43	5
Total	866	865	854	876	865	100
bulk density kg/m³	509	502	503	507	505	

Table 4 Average Primary Energy Costs of Raw and Auxiliary Materials and Average Bulk Densities in 7 AAC Factories in 1980 to 1983

4. PRIMARY ENERGY CONSUMED IN THE TRANSPORT OF RAW MATERIALS

The transport of the raw materials to the AAC factory must not be neglected in the overall energy calculation because it accounts for about 5%. Sand is the component used in the largest quantity in autoclaved aerated concrete. For this reason the location of the factory must be selected in dependence on the sand deposits which are available. The sand is transported to the seven factories over distances from 0.5 to 35 km. Hydraulic cement is transported over distandes between 32 and 166 km, lime over distances between 60 and 290 km and aluminum over distances between 90 and 600 km. The transport of aluminum is not significant in the energy calculation because aluminum is used only in small quantities. The average primary energy consumed for the transport of raw materials is constant and amounts to 74 MJ/m³. It has not changed from 1980 to 1983.

5. PRIMARY ENERGY CONSUMPTION IN THE AAC FACTORY

The production of autoclaved aerated concrete can briefly be described to consist of the following steps (see also Figure 1):

- The coarse raw sand is ground to a high fineness;
- the components sand, cement, lime and aluminum as an aerating agent are proportioned by means of a weighing plant and are intensely mixed in a mixer at high speed;
- the liquid mix flows into a mould having a capatity of several cubic metres and expands and solidifies in the mould to form green aerated concrete;
- the block of green aerated concrete is cut on a cutting machine with wires to bricks of the desired size;
- in the autoclave, the autoclaved aerated concrete as the end product is obtained by curing with steam under pressure.

By far the largest part of the production energy is consumed in autoclaving. In the other production steps, all of which require electrical energy, the grinding of sand is the largest power consumer. In the determination of the energy consumption by process chain analysis, the total electric energy consumed in the first four steps described has been determined. The kWh figure which has been read has been converted to a primary energy figure by a multiplication with the factor 2.56 in Table 1. Steam is generated in the several factories by the combustion of light or heavy fuel oil or natural gas and in one case of butane gas. The calculation of the specific energy consumption for autoclaving involves some inaccuracies because the steam generators supply in addition to the autoclaves other consumers in some cases and the consumption of the latter cannot always be exactly determined.

As an example of the primary energy consumed in the actual production of autoclaved aerated concrete, table 5 gives the figures of seven factories for 1983.

Factory	A	B	C	D	E	F	G	Average	%
Electrical energy	89	98	139	99	142	95	152	116	22,5
Autoclaving	374	284	364	394	496	375	504	399	77,5
Total	463	382	503	493	638	470	656	515	100

Table 5 Primary Energy Consumption in the Production of AAC in Seven Factories in 1983

On an average, the factories consumed 116 MJ/m³ electrical energy and 399 MJ/m³ autoclaving energy. As a result, the average consumption of primary energy per cubic metre of AAC having a bulk density of 507 kg/m³ amounted to 515 MJ/m³. 22,5 % of that energy were consumed in the generation of electrical energy. Owing to the high conversion loss involved in the generation of electric power, the electrical energy which was actually consumed amounted to only 9% (45 MJ/m³ or 12.6 kWh/m³).

The autoclaving energy has been substantially reduced from 1980 to 1983, as is apparent from Table 6. This has mainly been achieved in that the high-pressure steam was transferred from one autoclave to another. The consumption of electrical energy increased slightly from 1980 to 1983; this has been due in part to the increased automation in the factories. The total energy consumed in the production of AAC decreased from 670 MJ/m³ in 1980 to 515 MJ/m³ in 1983. This corresponds to a saving of 23% of primary energy in four years.

	Average values in MJ/m³			
	1980	1981	1982	1983
Electrical energy	86	104	112	116
Autoclaving	584	524	455	399
Total	670	628	567	515
%	100	93,7	84,6	76,9

Table 6 Primary Energy Consumed in the Production of AAC; Average annual figures for seven factories in 1980 to 1983

6. TOTAL ENERGY COSTS OF AUTOCLAVED AERATED CONCRETE

The addition of the PEC values for the raw and auxiliary materials, for their transport and for production results in the total PEC of autoclaved aerated concrete. The annual average values for seven factories in 1980 to 1983 have been compiled in Table 7. As a result of the saving of autoclaving energy, the average total PEC of AAC produced in seven factories descreased from 1609 MJ/m³ to 1465 MJ/m³. In 1983, 60% of the PEC of AAC was consumed by the raw materials, 5 % by the transport of raw materials, and 35% by the actual production in the AAC factory.

	Average values in MJ/m³			
	1980	1981	1982	1983
Raw materials	821	821	814	833
Auxiliary materials	45	44	40	43
Transport	73	74	73	74
Production				
Electrical energy	86	104	112	116
Autoclaving	584	524	455	399
Total	1609	1567	1494	1465
%	100	97,4	92,8	91,5

Table 7 Total Primary Energy Costs of AAC - Average annual figures for seven factories in 1980 to 1983

7. DISCUSSION AND OUTLOOK

Marmê has reported PEC of 1708 MJ/m³ for blocks of autoclaved aerated concrete having a bulk density of 550 kg/m³. When converted to the density of 505 kg/m³ of the concrete covered by the present investigation this corresponds to 1568 MJ/m³. The value of 1465 MJ/m³ obtained in 1983 is lower only by 100 MJ/m³ but is believed to be more reliable, particularly because Marmê has not taken the consumption of auxiliary materials into account.

Substantial savings of energy cannot be expected in the future because the possibilities of overflowing and heat recovery have been substantially entirely exploited. As regards the binders, it is expected that about 5% energy will be saved in their production in the near future (1990) and 10 to 12% on the long run. Updated PEC figures for the binders will have to be used in future investigations. Further savings of binders may be possible by the development of new formulae for autoclaved aerated concrete. In 1983 the figure for the factory having the lowest total PEC amounted to only 1307 MJ/m³ because the production in that factory required less binder than usual owing to the use of sand of high quality and to favourable other conditions.

Having primary energy costs of 1465 MJ/m² in case of a bulk density of 505 kg/m³, autoclaved aerated concrete compares favourably with other wall materials. In accordance with published figures (4), only pumice concrete and sand-lime bricks have slightly lower PEC values. Because autoclaved aerated concrete has a high heat-insulating capacity owing to its low density, it has a particularly favourable relation of primary energy costs to heat energy saving.

8. REFERENCES

(1) TUROWSKI, R. "Verbesserte Gebäudeisolation mit alternativen Baustoffen- Einfluss auf Heizenergiebedarf und Primärenergiebilanz", Internal Report STE B 2/76, KFA Jülich GmbH, 1976

(2) KINDLER, K. and NIKLES, A. "Energiebedarf bei der Herstellung und Verarbeitung von Kunststoffen", Chem. Ing.-Tech. 51 (1979), No. 11, 1125-27

(3) MARME, W. " Der Primärenergieinhalt von Baustoffen ", diploma thesis, Institut für Baustofftechnologie, Karlsruhe University, 1980

(4) MARME, W., and SEEBERGER.J., "Der Primärenergiegehalt von Baustoffen", Bauphysik 5/1982, 155-160; 6/1982, 208-214