Precast concrete block chimney units

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PREFACE

The performance of residential chimneys is of continuing interest to the Building Services Section of the Division of Building Research. For the past few years this section has been concerned with the fire hazard aspect of masonry chimneys and tests are being conducted on chimneys constructed of unit clay bricks and precast concrete blocks. Because of the variety of precast concrete blocks available and of their increasing use in chimney construction, this paper on the factors which affect the performance of these chimneys is a timely and valuable addition to the scant literature in this field.

The Division is indebted to Mr. D.A. Sinclair of the Translation Section of the National Research Council for preparing this translation.

Ottawa,
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N.B. Hutcheon,
Assistant Director.

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Summary

After tests were carried out on flues and chimneys at the Champs-sur-Marne Experimental Station, certain principles were established for improving the manufacture of lightweight concrete flue units.

At the same time, simple apparatus was developed for carrying out rapid heat-resistance tests on flue units.

The article includes a description of the research and the conclusions which can be drawn from it, and deals with the permeability to air, expansion and heat resistance of flue and chimney units, and the way in which the simplified heat resistance testing apparatus is used.

This article also includes details of some of the first results of tests which were carried out at the C.S.T.B. Experimental Station in order to establish the effect of the various parameters involved in the manufacture of concrete on its behaviour when subjected to heat.

Introduction

Not so long ago chimneys for venting combustion gases, generally made of clay and in most cases incorporated in the masonry of walls, had large cross-sections permitting effective cooling of the fumes, which conserved the flue while at the same time limiting the dangers due to the accumulation of soot.

On the other hand, such flues provided only mediorcre draft, although it was generally sufficient to ensure the functioning of relatively simple equipment with large flue gas outputs.

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* Tests carried out by M. Delahaye, engineer in charge of the "Chimneys Section" of the Champs-sur-Marne Experimental Station.

Gradually however, because of progress made in the design of heating equipment, it was necessary to reduce the flue cross-section in order to ensure the minimum required draught. This tendency, which was strengthened by space-saving considerations, especially in connection with tall apartment buildings, has been still further stimulated by the development of continuous burning, high-efficiency heating equipment and the increasing use of liquid and gaseous fuels.

On the constructive plane this development has led to the introduction and spread of the use of light chimney elements, i.e. chimney blocks.

At first these chimney blocks were made almost exclusively of clay, the classic material for flues; however, because of the last world war and the material shortages which followed, we have witnessed a parallel development in the manufacture of such units from concrete. Today, although a tendency appears to be arising towards the adoption of systems employing units of larger dimensions, or even totally different materials and techniques, these chimney blocks, whether of clay or concrete, still constitute the great majority of completed constructions.

On the official plane this same development has led to the issuance of a series of texts defining the conditions of design and construction of chimneys, of which we have kept our readers regularly informed.

Recently, all these texts have been assembled in the form of a resolution for application of Article 22 of Decree 55-1394 of 22 October 1955 laying down the general rules for the construction of dwellings; this resolution, entitled "Permanent heating and flue installations", supplemented by a circular establishing the particular specifications applicable to "Flues designed to handle several furnaces", was published under the joint signature of the Ministries of Construction and Public Health in the Journal officiel of 14 November 1955.

These latter documents, which lay down the conditions for the construction of chimneys and also express certain requirements relative to the nature of the materials entering into their construction, or their preparation for use, were issued with a view to ensuring the indispensable guarantees of safety to the purchasers.

However, they do not constitute a very effective obstacle to possible defects of quality and construction, and it is undeniable that at the present time the chimney is one item of a structure of which one cannot be very certain of the behaviour. One of the reasons for trouble, which incidentally does not spare the "traditional" materials, may perhaps arise from the fact that most of the chimneys are never used, which may have promoted a certain carelessness in the application of the rules of good construction. However, it is certainly not the only one.

Actually, chimneys which are structural units to which the known rules of strength apply, are also subject in use to certain conditions associated with their special function, conditions which are often neglected and which in any case have but rarely been the subject of serious study.

The resulting disorders, defects of draughts or tightness, degradation due to the appearance of stains or cracks, are for the most part the result of such negligence or ignorance.

The rules, based on the laws governing draught and on the experience of specialists, generally enable us to determine the causes of the first of these disorders and to remedy them: improper construction, defective seating or insulation of the chimney, improper connection or operation of the heating equipment itself, etc.

The mechanism of degradation due to staining is also comparatively well known, and while it is expensive to repair these disorders, it is nevertheless possible to foresee them and thus for the most part to avoid them by choosing a fuel suited to the characteristics of the chimney or of the material of which it is built.

Leaks, except where they result from deterioration of the chimney after long service, are the result of poor workmanship, or of poor or inadequately prepared materials and may be avoided by scrupulous observation of all the rules of good construction.

Cracking, which is an indication of progressive deterioration of the flue, is doubtless more serious and may endanger the health of the inhabitants. The problems posed by cracking are also much more complex.

It is known that cracking results for the most part from temperature stresses developing in the chimney, stresses which may vary greatly according to the properties of the materials employed and the manner in which they have been processed, or depending on the operating conditions of the flue.

Now, while the physical properties of building materials are well known at room temperature, they are much less well known at the temperatures prevailing in chimneys under operating conditions.

At a later date it is in any case always difficult to determine the exact quality of the units employed in a given construction or the methods that have been used in assembling them, so that the experience to be gained under these conditions from existing structures is rather limited.

However, the C.S.T.B., charged with defining the minimum acceptable standard of quality for non-traditional chimney units, has drawn up rules for approval on the basis of a functional thermal test, the text of which was made available to our readers in a preceding pamphlet.

Since that time we have had the opportunity of examining a number of examples on the basis of these rules and this has resulted in certain modifications of detail.

At the same time, in the light of hints derived from these studies we have pursued investigations with a view to eliminating as far as possible those causes of deterioration which can be attributed to the poor quality of the chimney-building materials.

The quality of the structural elements of course constitutes only one aspect of the problems involved in chimneys and could not, by itself, solve all of them.

The work undertaken in this connection is not yet finished. We thought it would be useful, however, to inform our readers of the preliminary results without further delay.

Development of the Rules for Approval

Reiteration of the approval conditions

In Cahier No. 238 we published the Interim Rules on the authority of the commission responsible for the approval of non-traditional chimney units.

In the absence of precise data on the behaviour of materials under the operating conditions of chimneys, these rules had been based on tests of an arbitrary nature and more particularly in the light of a study of concrete blocks, which represented non-traditional units in current use.

The thermal conductivity of these units could be considered known in sufficiently close approximation so that no special test would be needed to measure this. Furthermore, although little is known concerning the conditions of resistance of concrete to the chemical agents in flue gas, experience would appear to show that the concretes currently being used in the manufacture of chimney blocks were sufficiently stable from this point of view so that serious deterioration need be feared only in very exceptional cases.

The tests finally retained in the rules for approval to determine the suitability for employment of the units in question were thus limited to a test of thermal strength and a test of air permeability.

Furthermore, in order to take into account the fact that the exact part played in the behaviour of the unit by various factors involved in their manufacture was unknown, these same rules pointed out that each type of unit and each particular method of manufacture would have to be the subject of separate examination as far as approval was concerned.

A certain arbitrariness doubtless prevailed in choosing the above criteria of judgment. Doubtless the fact that a product satisfied them did not mean that it was the best available nor that the user would necessarily be protected from all failure.

However, it could be accepted that such as they were they constituted a first effective selection to the extent that the samples tested could be declared to reflect accurately the quality of manufacture in question, and that this quality would be guaranteed over a certain length of time.

Lessons drawn from the application of the rules for approval

Since the time that these rules were first adopted, during the year 1958, a considerable number of products have been brought to our attention. The first tests quickly showed that these products were of widely differing quality and that some of them by no means showed the homogeneity necessary for any test to be of real practical value.

Because of the methods of execution adopted for the thermal test, methods which involved considerable delays for processing or drying, and in view of the unfortunately limited capacity of the testing equipment, the chimney-testing laboratory of our experimental station soon found itself flooded with products many of which were not worth testing because of their poorly-defined character.

It thus seemed essential to complement the rules for approval in force by specifications which could take the place of a preselection and enable us to eliminate from the start products which were obviously inadequate from the point of view of homogeneity.

Preliminary identification tests

With this in mind manufacturers wishing to have their products subjected to the long and costly thermal test were asked to apply beforehand certain simple tests which could be executed in any conventional materials testing laboratory so as to furnish proof that these products were already of sufficiently definite and constant character.

The tests required are compressive strength tests and the determination of the apparent density of the concrete. The scatter of the results from these tests, carried out on at least seven whole chimney blocks selected arbitrarily from current production, permits an estimate to be made of the constancy of the concrete used in the products and to define its average characteristics.

Identical tests are again carried out at the experimental station, this time on chimney blocks selected from those obtained at the factory under our supervision for the approval tests themselves. From the results of these we were able to confirm by comparison the homogeneity data from the preliminary tests and to verify the constancy in time of the products in question.

These measures permit the desired preselection but are still of no use as far as products not coming up to standard are concerned, since they do not provide the manufacturer with any means of tracking down the reasons for the inadequacy nor with the data he needs in order to remedy the situation.

The causes of the trouble may vary greatly. This is because the manufacture of concrete products is the result of a series of operations on products whose quality itself cannot be absolutely constant.

Many factors may intervene, unless one takes care, to upset a quality which is assumed to be assured by adopting an apparently constant working routine, for example, variation in the raw material, accidental departures from exact proportions, the effect of very variable climatic conditions, etc. Even careful supervision and long experience are not always sufficient to reveal such irregularities soon enough so that the required corrections can be applied to the production in time to be effective.

The only way in which this goal can be obtained is by constant control testing so as to assure at all times the normal observance of the rules laid down at the beginning.

Manufacturing checks

The rules for approval, from the time that they were put into force, drew the attention of manufacturers to the value of such checks, establishing them in principle, but leaving to the individual a choice in defining their precise nature.

However, the experience gained from the first studies made under these rules has shown that the effectively executed checks which applied substantially to the finished product (permeability), were still inadequate.

We have thus been induced to define precisely a certain number of supplementary checks and to make the manufacturers responsible for carrying them out if they wish to obtain approval for their products.

In all, the checking of a given production must satisfy the following conditions:

The tests involved must be simple and few in number, while at the same time covering all possible sources of error having regard to the method of manufacture being employed. The results must, moreover, be capable of permitting improvements in the conditions of this manufacturing method in the sense of a greater assurance and still better quality.

On the other hand, to be effective the check should be frequent without placing too great a burden on the person who is responsible for it. It must therefore be simple and quick, especially as any delay in checking means also a delay in applying any corrections that may be required and will thus affect the desired regularity.

Finally, to be significant the results of the check must give a good definition of the mean quality of the product at the exact instant of checking. In order to be certain that this condition is fulfilled, therefore, the choice of samples taken from the production line and the conditions of execution of the tests as such must themselves be subject to precise and well-defined precautions from the outset.

In the case of chimney blocks the checks finally settled upon relate to the following three main stages in the production chain: (1) the raw materials (aggregates); (2) the manufacturing process itself (preparation and casting of the concrete); (3) the finished products.

These should be sufficient to reveal the source or cause of any accidental irregularity and to determine who is responsible for it.

The frequency of the checks depends on the number and nature of the factors involved in the various stages of manufacture.

Raw material checks

Where the raw materials are concerned every supply situation represents a particular case. The suggested frequency of checking is daily, but in practice longer intervals can be adopted after tests not long after starting up have enabled the manufacturer to estimate the uniformity of shipments from his supplier.

This check is limited to a sieve analysis and measurement of the apparent density of the constituents.

Manufacturing checks

The checking of the manufacture as such (mixing of the concrete and casting) is the most important, because this is the check which will give rise to the application of the all-important corrections and it must therefore be the most frequent. A daily check is mandatory.

A further justification of this frequency is the fact that this is the point where the human factor is most fully involved.

The processing check is the simplest one possible, merely weighing. This weighing of the products at a particular moment in their manufacture where the strength and ultimate quality are already in fact inherent in the still green concrete, provide an immediate indication of the uniformity of manufacture.

It is supplemented by a sieve analysis and verification of the proportioning of water of mixture. This check is necessary if one wishes to pin down the cause of any irregularity revealed by weighing, or to determine whether the corrections applied on the basis of data furnished by previous checks have been properly conceived and carried out.

Check of the finished product

The test on the finished product ready for shipment adds a final sanction, as it were, to the result of the other checks.

It is logical for this test to be based on the values that best characterize the suitability for use of the manufactured units, taking into account the specific purposes for which it is intended.

In the present case, however, these characteristic values, namely permeability and especially thermal strength, are not of a classical order. A check of them has simply been recommended, but not demanded, since as yet no one has been able to design a simple standard measuring apparatus.

Obviously, all the checks described above, which constitute a certain burden on whomever is responsible for them, are of no value unless the indications given by them are studied and exploited subsequently with a view to improving the quality and the yield of the plant. The simple fact of having applied them, without seeking to draw any information from them is a sheer waste of time and money both for the manufacturer and for the person charged with carrying them out.

Conclusions

We may hope that the rules for approval, supplemented by all the above conditions, preliminary tests and manufacturing checks, are a means of selecting products having the desired qualities of definition at constancy.

Furthermore, the approval tests themselves constitute a second test of selection, this time in relation to the suitability of the particular material examined for use.

However, this procedure still has the disadvantage that its application alone enables us to define a minimum quality standard, but does not yet produce the data required in order to raise this standard.

This is due mainly to the nature of the thermal test involved in the general appreciation. This test, indeed, is difficult to exploit in any practical manner.

Primarily, the methods of execution and the criteria of judgment applied (test chimneys provided with a coating, and examination of cracks at the end of the test) make it in practice an "all or nothing" test admitting of no gradations.

Moreover, some of the parameters involved, such as the conditions of assembly of the chimney being tested, are difficult to define rigorously. Then again, the state of the chimney at the end of the test, i.e. at the time of judgment, is the result of the effect of many factors (composition of concrete, shape of block, etc.) between which the test is unable to discriminate and the respective contributions of which cannot afterwards be defined.

Another difficulty encountered in exploiting the results of the tests made for approval purposes derives from the fact that the identification tag applied to the tested products is based only on data furnished by the manufacturer. These data define the mean characteristics of the tested products closely enough but they do not always give the information required with respect to their "history" up to the time of casting, and doubtless this history is never strictly the same from one product to another.

Finally, in view of its complexity, or because of the inadequacy of knowledge of the products which are subjected to it, the test permits of only two results, acceptance or rejection. In the event of failure, in particular it does not enable us to inform the manufacturer of the reasons for the failure, as he may legitimately expect, nor of ways for overcoming the difficulty.

Therefore while continuing to study the products presented for approval according to the above rules, we are also seeking means by which we will be able to remedy this deficiency.

With this in mind we have undertaken to conduct research on products made in our own plants with the following two main purposes:

The development of a thermal test which will be rapid, reproducible and at the same time informative, and which will permit effective classification of the products with respect to quality and will be simple enough to be installed by every manufacturer in his plant as a means of checking, and of final quality verification;

A basic research programme with a view to determining the behaviour of concretes in relation to the conditions prevailing in flues, especially from the standpoint of temperature, and to discover the effect on this behaviour of the various parameters involved in the make-up of the concrete, i.e. type and proportion of binder, aggregate and water, proportioning of mixture, pressure conditions, etc.

Although it is still too early to be able to draw definitive conclusions from these studies, or more important, to give exact proportioning of ingredients, it seemed to us that the preliminary information would be of interest to our readers and we are therefore publishing it with this in view.

Research Carried out at the Experimental Station

The functional test, provided a good choice of the conditions determining the "function" is made, is the form of test which has the best chance in the long run of reproducing the actual behaviour.

The simplified test, on the other hand, by definition abstracts certain parameters that play a definite part, the extent of which must be determined.

In the present case, the desired simple and rapid test could scarcely involve anything but a test on a single unit, block or specimen. Before the procedures could even be considered it was necessary to see whether it was indeed possible to consider the test as other than arbitrary.

The aim of such a test is the selection of material that can be used to build chimneys that will meet the conditions of permeability, strength with respect to heat, corrosion resistance and thermal insulation.

It is probable that the last two characteristics are specifics of the material and are affected but little by the conditions of assembly. This is by no means the case, however, for the first two characteristics.

The most frequent form of deterioration of chimneys consists in cracking either of the elements themselves or of the joints between them. It seemed necessary, before beginning development of a simplified test which would take into account the conditions of assembly, to carry out preliminary tests which would throw light on the magnitude or mechanisms of these deteriorating influences, in particular:

The mechanism underlying the appearance of horizontal cracks in the joints and the importance to be attached to them, especially from the standpoint of permeability;

A study of the effects of the assembling conditions, especially the manner of incorporating the chimneys in the building, on the stability of the elements themselves.

Finally, in view of the diversity of information which we had collected on the characteristics of flue gas, especially from the point of view of their temperature, we thought it would be useful to carry out some preliminary tests on the functioning of chimneys under actual conditions in order to verify the significance of the procedures hitherto adopted in tests of thermal strength.

Preliminary tests

Tests of actual operation

For the purposes of these tests we attempted to get combinations of furnaces and chimneys which would as far as possible represent the characteristics of an average domestic heating installation.

The tests were carried out in the experimental building of the station on a flue of pozzolana concrete block with 5 cm (1.96 in.) solid walls and a 2 cm (.785 in.) plaster coating, the thermal insulation of which could be assumed to correspond more or less to that of chimneys in current use.

The total height of the chimney measured from its base at the furnace connecting level was about 6 m (19.7 ft).

After the coatings had dried sufficiently we successively connected this chimney to various heating equipment of widely differing design, including a continuous-burning direct-draught stove, a continuous-burning indirect-draught stove and finally an oil stove.

In the first two cases the testing was carried out at first with a semibituminous coal and then, in a second test, with dry wood.

All these tests were carried out with natural draught, the controls of the stoves being locked at the maximum; however, at the end of a period of several hours' operation under these conditions, when the temperature conditions in the chimney reached steady state, we artificially increased the rate of combustion by keeping the ash pit doors open (in the case of the direct-draught stove fired with wood the "ash pit door-open test" was terminated after only 80 minutes)

Thermocouples installed in the flue at the level of the first chimney block enabled us to keep a record of the flue gas temperatures and those of the internal and external walls of the chimney throughout the entire tests. The flow rate of the flue gas was also estimated for each test by means of a pitot tube.

The results of these tests are assembled in Table I.

They confirm that continuously-burning stoves of this type, widely used at the present time, emit flue gas of relatively very low temperature, not exceeding in our tests, even under conditions of accidentally accelerated draught, 400°C (752°F).

As might be expected, the highest flue gas temperatures were obtained from the burning of dry wood, but even in this case the observed wall temperatures are still quite low - 320°C (608°F) for normal maximum draught, and 390°C (734°F) for the accidental operating conditions with the draught door open.

This combustion of wood, giving rise to the given draught conditions for the greatest outputs of flue gas, is also what produces the fastest rise in temperature. As an indication, the severest conditions obtained in the case of the direct-draught stove with open ash pit door are given in Fig. 9, showing the increase of temperature of the internal wall of the first chimney block as a function of time.

Most of the information contained in the existing literature on the temperatures prevailing in flues relates only to the maximum temperatures attained by the flue gas, depending on the type of furnace or the nature of the fuel. Without precise indications defining the conditions of thermal exchange between walls and flue gas no conclusions can be drawn about the corresponding temperatures of the walls.

We have nevertheless found that the flue gas temperatures given substantially confirm our own results, at least as far as the fuels giving the hottest emissions are concerned, namely wood or fuel oil.

The temperature attained by the wall of a flue in the presence of flue gas of a given temperature can indeed vary within wide limits depending on the rate of flow of the flue gas, the state of the internal surface of the chimney and the thermal resistence of the walls. Moreover certain accidental conditions such as chimney fires, certainly give rise to temperatures that are much higher than those occurring under normal conditions.

However, except for accidental cases of artificially accelerated draught due to improper operation of the heating equipment, or to service accidents properly speaking, we have assumed that the temperature of 320°C (608°F) could be considered as representing an upper, acceptable mean of the internal wall surface temperature of a chimney in service.

The observations made in the course of numerous thermal tests conducted according to the procedures defined by the rules for approval, show that this temperature of 320°C (608°F) is also substantially that attained by chimneys in the course of the 500°C (932°F) test at approximately 1.50 m (4.9 ft) from the base course. We did not think it necessary at present to change its value.

Study of the Effect of Assembly Conditions on the Behaviour of the Concrete Blocks

Description of chimneys tested

Choice of concrete block characteristics

Useful comparative information cannot be derived from a series of tests unless we know in sufficient approximation what are the various factors that may enter into the final results. For the purposes of the present study it was particularly necessary, if we were to be able to interpret the results obtained with every certainty, to know the conditions that had prevailed in the manufacture of the chimney blocks being tested, their age at the time of the tests, the conditions under which they had been stored between the time of manufacture and the time of testing, etc.

Some of this information, as we have already stated, cannot be obtained with adequate precision from the present commercial manufacturers. In order to verify or pin down the conclusions which already appear to present themselves from the results obtained on the widely varied products examined for purposes of approval, we therefore manufactured concrete blocks ourselves, seeking to reproduce as far as possible the conditions of an average commercial manufacturing process.

Because we wished to obtain initial usable results as quickly as possible and did not wish to go on multiplying the number of tests indefinitely, we disregarded some of the important factors at the beginning such as the character of the concrete constituents or the form of the casting.

For these first tests we restricted ourselves to the use of pozzolana concretes, an aggregate which is currently used in practice and one of which the physical and mechanical characteristics at least at room temperature, are well known.

These concretes were cast in the form having solid walls of 5 cm (1.96 in.) thickness and a cross-section of 20 x 20 cm (7.85 x 7.85 in.) (Fig. 2), standard products in themselves and known from experience to be among those which are most affected, other things being equal, by the temperature.

The binding material used in all cases is a Portland CPB cement, class 250/315, the addition of fine aggregates, when necessary, being made with fly ash.

The compositions of the various mixtures prepared are those indicated at the top of Table I; the sieve analysis curves of these mixtures are given in Fig. 3.

All these mixtures were prepared from a pozzolana of the same origin and according to the same procedures, in a vertical mixer of the same type used currently in factories.

They were then cast in a mechanical, lever-operated machine equipped with a high frequency vibrator applied to one of the mould faces. The principle of this machine corresponds to that of the "vibromouleuses"* used in the factories.

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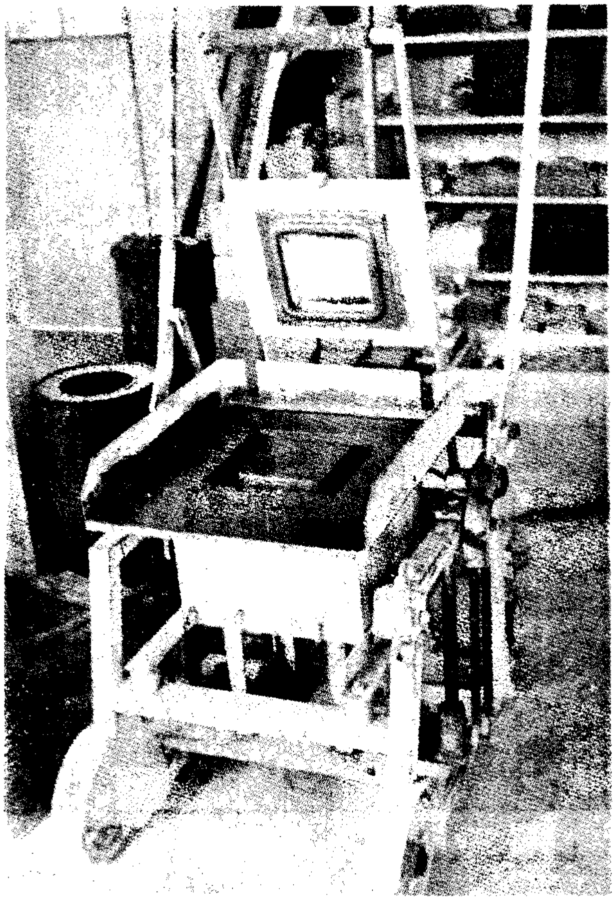
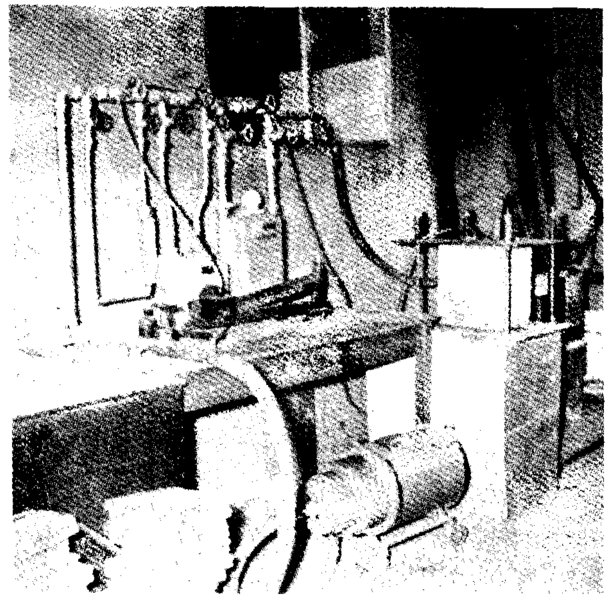
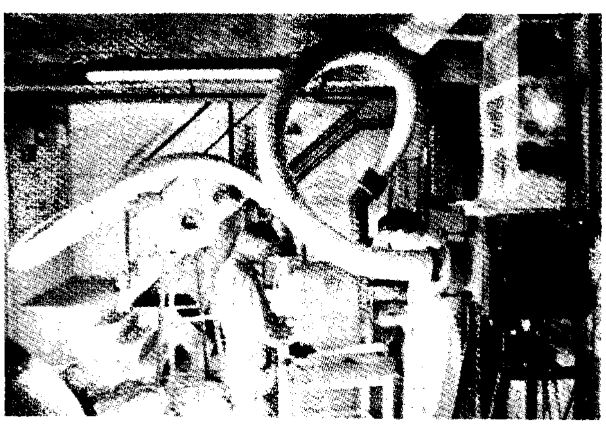
* Vibrator moulds (trans.)



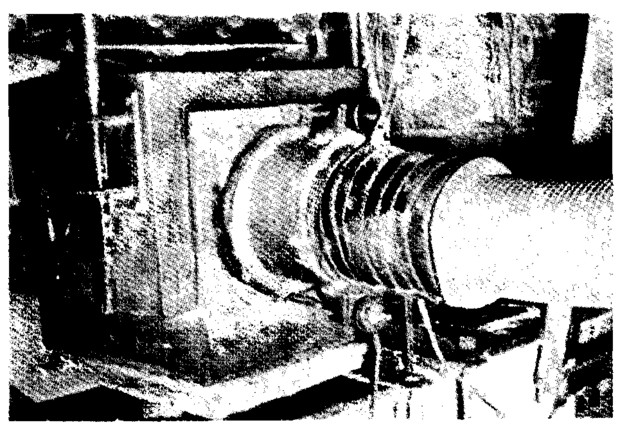
Machine used at the Station for the manufacture of test blocks



Test of permeability of individual blocks. General view of installation



Test of chimney permeability. General view of the installation



Test of permeability: Detail of connection to metal coupling sleeve leading into chimney

The results of the approval tests appeared to show in a general way that products permeable to air have better thermal strength than impermeable products; as we wish to determine the basis of this impression and also because we wish to pin down the relationship that might exist between the air permeability of the separate unit and that of the chimney in service after it has been plaster coated, we tried to obtain as wide a variety as possible of products from this point of view.

Three methods have been developed to achieve this purpose. They are, choice of the aggregate composition of the mixture, the conditions under which pressure is applied to the concrete, and finally a subsequent correction by application of a coating of mortar on the interior or exterior faces of the chimney blocks after they have been produced.

The main characteristics of the chimney blocks thus produced have also been listed at the top of Table I. The characteristics of a number of additional chimney blocks which were tested for approval and which also figure in our study are indicated at the top of Table II.

Conditions of assembly

After storing under shelter in conditions kept as constant as possible for a period of not less than three months, the chimney blocks manufactured by ourselves were taken to the chimney testing building which we have already described to our readers in a previous brochure.

The construction procedure is as follows:

Each chimney stands on a metal plate which rests in turn on two horizontal iron T-bars embedded in a masonry wall. The ends of these T-bars are joined to the ceiling of the storey by metal tie-beams which make the assembly rigid.

For easy disassembly and observation after testing the concrete blocks are assembled with plaster joints.

The flue is built vertical with no deviation over its entire height. It consists of chimney blocks only over a height of 3.30 m

(10.8 ft), beyond which it is completed up to a height of 6.50 m (21.3 ft) by a pipe of asbestos cement.

These chimneys, depending on the particular case, either stand completely free or are joined to the floors by a plaster caulking at floor level. In some cases the same chimney was subjected to several successive tests, some before caulking and others after (see Table II).

The chimneys assembled from concrete blocks being tested for approval were employed in the same experimental apparatus. In this case, however, the assembling procedures differ slightly from the foregoing.

The chimneys in this case are again assembled vertically without bends, but now they extend over the entire 6.50 m (21.3 ft). They are again joined with plaster, but as they are always backed by the masonry they are clad with a coating of plaster of 2 cm (.785 in.) mean thickness and are caulked at the respective floor levels (see Table III).

Character of tests and execution procedures

After sufficient time had been allowed for drying the assembled chimneys were subjected in succession to a measurement of permeability to the surrounding air, to tests of thermal strength and finally to two new permeability measurements carried out on a chimney while hot and after cooling. In the course of the thermal test an attempt was also made to estimate the extent of chimney movements due to temperature variations.

At the same time the concrete blocks used in the construction of these chimneys are subjected to identification tests bearing on the following characteristics:

apparent density of concrete, and homogeneity;

air-permeability of uncoated block;

air-permeability of block after coating with plaster 1 or 2 cm (.392 in. or .785 in.) in thickness.

The procedures adopted for the various tests will now be described.

Air-permeability

To measure the permeability we employed fans and flowmeters, the characteristics of which were chosen as a function of the surface areas of the units being tested. In our tests, the maximum outputs of the flowmeters employed were 10 m^3/hr (5.9 ctm) and 50 m^3/hr (29.4 ctm), respectively, for the test on the single concrete block and for that on the chimney, at a pressure of 10 mm (.394 in.) water. The minimum permeability coefficient discernible by these apparatuses were of the order of 1 and 5, respectively.

The apparatus is shown schematically in Fig. 4.

The air compressed by the fan is introduced into the unit to be tested (block or chimney) through an airtight duct and sealing device, the other end of the unit is also rendered airtight.

The flowmeter in the input air line between the fan and the specimen permits calculation of the quantity of air passing in a given time through the walls of the specimen.

A water manometer continuously records the pressure prevailing within the volume bounded by the chimney block and the top and bottom airtight covers. During the tests this pressure is kept in the vicinity of 10 mm (.394 in.) water.

In the special case of the chimney test the bottom joining these is the same as that used as a flue gas collector in the thermal test. It has been built so as to permit very rapid connection of the air input duct required in order to carry out a permeability measurement on the still hot chimney directly after the thermal test.

The results of these tests are put down in the form of an air-permeability coefficient:

$$k = \frac{Q.e}{P.S.t}$$

where $\frac{Q}{t}$ = flow of air in cm^3/min;

S = mean side area of unit tested in cm^2;

P = air pressure in g/cm^2 or cm water column;

e = total thickness of material making up the walls of the unit in cm.

The coefficient K thus defined represents the volume of air passing through a wall thickness of 1 cm under a pressure of 1 cm water, measured over a unit surface of the wall in question; this is, in fact, a specific magnitude of the materials constituting the unit being tested.

Thermal test

The thermal tests were carried out with a flue gas generator of the type described in principle in our Cahier No. 238. This apparatus was employed according to the procedures laid down in the rules for approval. We shall reiterate the essentials of these here.

The gases produced by an oil burner are introduced into the chimney through a metal sleeve which has already been mentioned briefly in connection with the permeability test. The purpose of the sleeve in this case is to avoid direct contact of the flames with the block and to ensure adequate mixing of the flue gas. The burning rate is controlled in such a way as to obtain the following conditions at a point situated 0.10 m (3.937 ft) below the course of the first concrete block in the axis of the chimney.

First of all the temperature of the gases is brought within 5 minutes from the room temperature to 400°C ± 10° (752°F ± 18°); this temperature of 400°C (752°F) is maintained for 1½ hours. The flue gas generator is then turned off for about 2 hours.

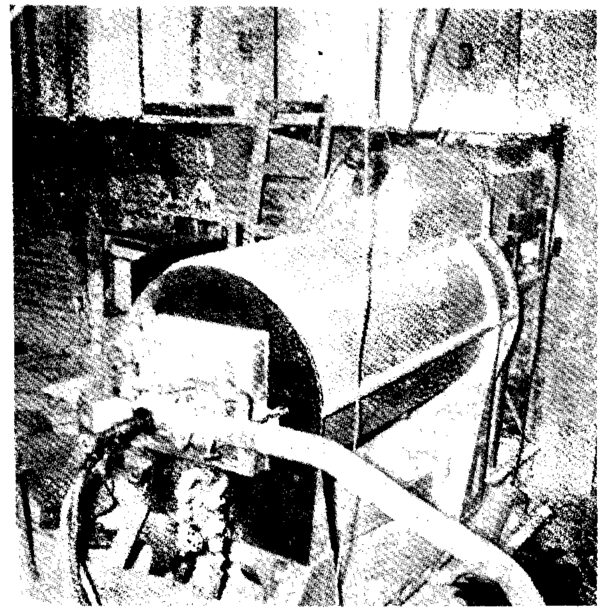
After this time the test is resumed, the temperature of the gases now being brought up to 500°C ± 10° (932°F ± 18°), again within 5 minutes; this 500°C (932°F) temperature is maintained for 1½ hours.

At the end of this second heating period the generator is again turned off and the flue is allowed to cool naturally.

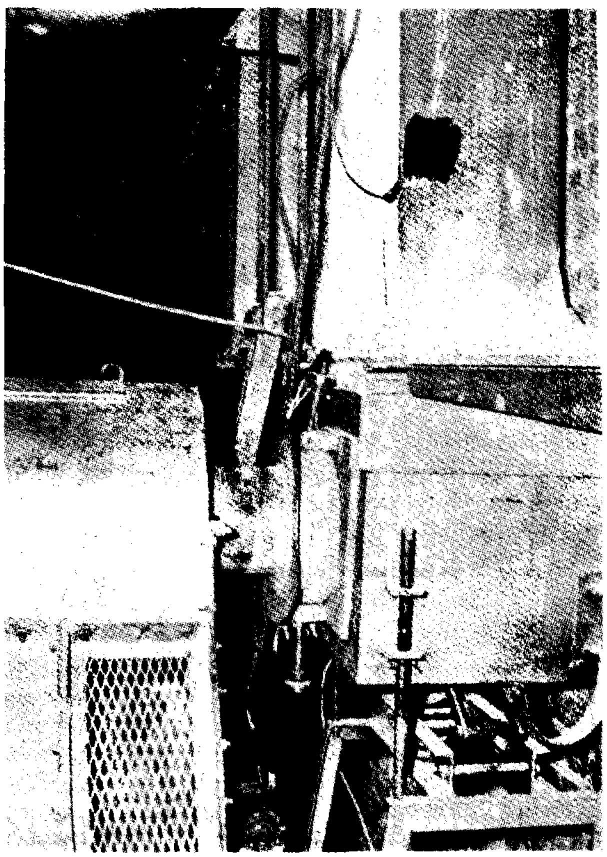
For all the tests the flow of gases into the flue was maintained at a value as close as possible to 140 m^3/hr (82.3 cfm).

The temperatures of the gases and walls were checked during the tests by means of thermocouples distributed at various points over the height of the flues.

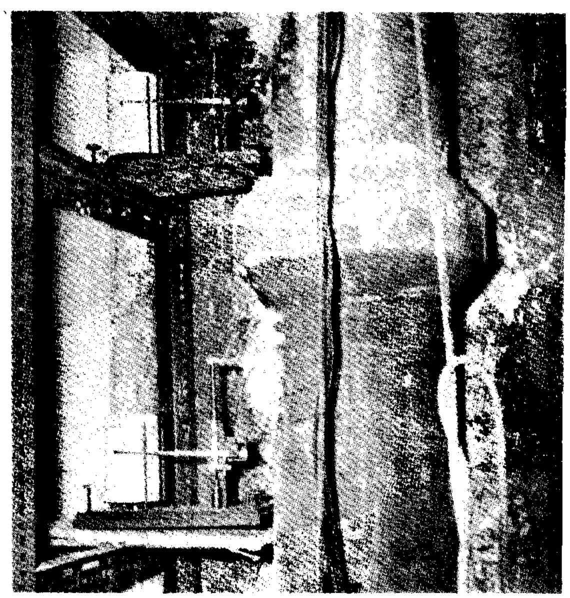
Fig. 5 is a schematic diagram of the installation, showing the placement of the thermocouples.



Thermal test on a chimney.
View of a flue gas generator



Thermal test: Detail of connection to the metal sleeve at the bottom of the chimney



Check of dimensional variations. Detail showing mounting of recording deflection gauges

In order to estimate the behaviour of the chimney during the test the appearance of cracks or other anomalies is noted as they occur; at the end of the test, after complete cooling and, where applicable, execution of a last permeability test, the chimney is dismantled in order to permit detailed examination of the internal walls of the blocks.

Dimensional variations

With a view to getting the maximum amount of information from observations of the behaviour of chimneys we also measured in the course of the thermal test, the amplitudes of the movements of some of the chimneys as a function of the variations of temperature.

These checks were made with the aid of deflection gauges set against asbestos cement plates which were sealed into the plaster on the external walls of the flues. These apparatuses were mounted on pedestals, themselves supported on the floors of the experimental building which in first approximation were sufficiently rigid and non-deformable.

Three points of measurement were selected situated at 0.40 (1.312), 1.70 (5.58) and 3.00 m (9.84 ft), respectively, above the base course of the chimney. A similar control apparatus was also applied beneath the metal mounting plate in order to verify its stability.

The locations of these apparatuses are indicated in Fig. 5.

Such a check, which is somewhat crude, could not of course take the place of a measurement of the coefficient of expansion of the chimney. It appeared adequate to us, however, to furnish approximate, comparative indications of the apparent total expansions of the various units tested.

Results and conclusions of tests

The results obtained have been assembled in Tables II, III and IV.

Table IV gives the results of tests carried out on single concrete blocks showing high permeability, with a view to determining the air-tightness conferred by the plaster coatings, depending on their thickness.

Tables II and III, respectively, give all the results obtained on chimneys assembled from concrete blocks manufactured at the Experimental Station and concrete blocks examined for approval.

Permeability

(a) Permeability of materials themselves, concretes and coatings

The results in Table IV show the effectiveness of plaster coating from the point of view of permeability.

The results at the bottom of this table relate to concrete blocks showing a very open structure similar to that of the cellular expanded concretes, and the figures obtained on these coated concrete blocks in fact characterize the permeability of the plaster coatings themselves.

Comparison of the permeability results obtained on certain concrete blocks of the same composition uncoated and coated with plaster (Table II) confirm the fact that even a very defective permeability can easily be corrected by this means.

From all these results together it can be stated that in the absence of any local disorder the air-permeability of a chimney in operation is not attributable to the permeability of the apparent coated faces, and that for chimneys carefully coated on all their faces the permeability of the supporting concrete block material itself is only of minor importance.

Rules of good construction further require that the spaces between two flues placed side by side or between flues and backing walls should be filled with mortar.

However, it must be recognized that in reality this precaution is hardly ever observed, and the coupled backing surfaces or surfaces of contact between flues are left bare.

Under these conditions, which are also those of our tests, it is obvious that the permeability of the concrete block material does indeed play an important part in the permeability of the chimney.

(b) Permeability of the chimney before the thermal test

The results of the measurements permit the following conclusions to be drawn.

In the first place, because of incomplete filling of the space between the backing surface and the wall none of the chimneys made from concrete blocks of high permeability is itself airtight. This chimney surface, imperfectly protected, allows a certain amount of air to pass through, which always finds a means of escaping either through the supporting masonry which cannot be considered airtight, or along this masonry.

It may be noted on the other hand that the coefficient K characterizing the mean total permeability of the materials making up the chimney is always greater than the coefficient characterizing the concrete blocks taken seaparately, when this concrete is itself comparatively airtight, and that the inverse situation exists when this concrete is very permeable to the air.

For the particular conditons of assembly adopted in our tests there seems to be a threshold, difficult to determine exactly, below which the permeability of the chimney is greater than that of the concrete block, while above it the reverse situation holds.

This is because the joints between the concrete blocks, although executed in our tests with exceptional care, are not themselves airtight, and the permeability of the chimney even when built with airtight concrete blocks and coated on three surfaces, is still influenced by the permeability of the joints on the backing surface.

(c) Permeability of chimneys after the thermal test

After the thermal test the chimneys most often, in varying degrees, show local cracks either in the joints or in the concrete blocks themselves.

When the chimney is hot the majority of visible cracks are those involving the concrete blocks. Generally speaking they are few in number and always close more or less as the chimney cools.

After cooling, however, the most numerous cracks are those localized in the joints. They may be of varying size, depending on the conditions under which the chimney is joined to the building, ranging from capillary cracks to cracks up to 1 mm (.04 in.) in thickness.

These cracks do not appear to have any substantial effect on the overall permeability of the chimney.

The permeability measured on the chimney while it is still hot even seems very slightly lower than that obtained on the same chimney before the thermal test. This might be due to an improvement in the tightness of the joints, i.e. as a result of the compression stresses produced by the high temperature.

After the thermal test, on the other hand, the permeability again appears to increase slightly as the chimney cools and to return to a value very close to the initial one measured on the chimney before the thermal test.

Measurements carried out for verification purposes on separate, uncoated concrete blocks with and without cracks, confirmed that the cracks, except in cases of real breakage, had no appreciable effect on the total permeability of the product.

The results of these permeability measurements are summed up in the following remarks.

Although the coatings applied to the concrete clocks are, by themselves, airtight for all practical purposes, the masonry chimneys as realized in practice have no chance of attaining a satisfactory impermeability to air unless they are constructed to begin with from chimney blocks which are equally airtight.

Assuming that this condition has been satisfied, the required impermeability still cannot be obtained unless very great care is also applied in assembling the units, especially in the execution of the joints and indeed <u>all of the joints</u>. It should be remarked here that our measurements indicate only a mean total permeability of the chimney, and that actually where a localized malfunctioning occurs at one or more joints, the quantity of gas that can diffuse into the space where this malfunctioning occurs may be much greater than the measured permeability would appear to indicate.

As long as cracks remain sufficiently fine, and fortunately the majority of those observed in practice fall within this category, they do not appear to have any serious effect on the impermeability.

The only ones that constitute a serious danger are larger ones, say of the order of 1 mm (.04 in.) width at the outside surface, indicating either a break in a concrete block or the total separation of a joint.

Finally, the permeability of a chimney is basically a function of the care with which it is installed, a factor which can scarcely be estimated in any precise manner by tests.

The permeability test of the chimney, which does involve this parameter incidentally, is doubtless of value as a check, but cannot be considered as a basis for the selection of the concrete block.

From the standpoint of the quality of building materials the only characteristic which has a bearing on the permeability of the chimney is the permeability of the concrete itself of which the concrete blocks are made. It is more accurate and more correct to determine this value from the separate concrete blocks.

Expansion and thermal strength

(a) Effect of the concrete block composition on the behaviour of the flues

Let us recall first of all that in our tests the chimneys are subjected to the action of a flue gas flow, and temperature which are reproduced identically at each instant from one test to the next.

Under the effect of these identical heating conditions the temperatures of the flue walls, which are already variable with height, can of course attain different values depending on the characteristics of the materials constituting them. Moreover, the concretes or mortars subjected to heat always undergo some shrinkage owing to the expulsion of some of the water contained in them.

It is important to note, therefore, that the dimensional variations indicated by us actually represent only a total apparent elongation of flues resulting from these particular conditions and are not necessarily directly proportional to the coefficient of expansion pertaining to the materials constituting them.

Having said this, we find by comparing all the results obtained on the free standing chimneys (Table II), that the total elongation of the flue increases with increasing density of the concrete blocks, or, what amounts to the same thing, increasing compactness. The differences are considerable since they cover a range of ratios from 1 to 4 when the density of the concrete increases from 1.23 to 1.77 (chimneys 1 to 6, not fixed in the floors).

In these same chimneys the cracks found at the end of the test are larger and more numerous for the denser concrete blocks. Only the lightest concrete blocks, those of a density of less than 1.52, show practically no crackage (uncoated blocks).

In addition, these increases in the dimensional variations and the development of cracks appear to be of the same order when the increased density of the concrete results from a supplementary addition of fine aggregates and also when it is a consequence of a greater compression applied in the casting.

On the other hand, the results obtained on the chimneys of series 1, 2 and 3, show that the application of a rich interior or exterior mortar of high mechanical properties to a light concrete block also increases considerably the sensitivity of the material to heat; all these chimneys, in fact, showed a considerable apparent expansion and serious crackage.

In this respect the least objectionable solution still appears to be that of an external coating, doubtless because it corresponds, other things being equal, to relatively uniform distributions of temperatures over the thickness of the wall, and also because to some extent it exerts a hoop effect on the product.

We may note, finally, that the observed apparent elongation of chimneys fixed in the floors is always very slight regardless of the concrete composition of the concrete blocks employed.

(b) Effect of the manner of installation

As Tables II and III show, most of the chimneys are cracked by the end of the thermal test. The size of the cracks, the time of their appearance and their location differ depending on whether the chimney in question is joined or not to the building as a whole by caulking at the floor level.

Furthermore, these caulking conditions have different effects on the cracks localized at the joint level and those affecting the chimney blocks.

Cracks at the joints

Only chimneys 1 and 2, free-standing and assembled from the lightest concrete block and left uncoated, showed no cracks at the joint levels either in the course of the test or after cooling. All the other free-standing chimneys had capillary cracks at practically every joint. After the chimney had cooled these cracks closed up again.

The joints of the chimneys fixed by caulking at the floors also showed some capillary cracks during the course of the tests, but in this case they were less systematically distributed over the height of the chimney. In all cases, however, except chimney 2, at least one of these cracks in each space between floors, most often situated about half way between the floors, showed up on cooling and attained a width of the order of a millimetre or more.

The capillary cracks observed in the first case result from the shearing stresses produced at the interface between the concrete of the chimney blocks and that of the joints by reason of the intrinsically different characteristics of these materials both as a function of the expansions and of the shrinkages.

They have the same origin as the cracks sometimes observed in the masonry joints of walls or partitions, but are more systematic because of the greater amplitude of the temperature variations. They can also appear, and sometimes do appear in practice, even before the chimney begins to operate, for example, if the concrete blocks employed are too green when assembled and are coated under poor conditions or prematurely.

When the chimneys are fixed in the floors these cracks resulting from horizontal shearing stresses no doubt do occur but are not apparent when the chimney is hot because of the vertical stresses developed in the chimney by the temperature.

These vertical stresses, due to the resistance to expansion provided by the floors are certainly of considerable magnitude in relation to the amplitude of the movements displayed, other things being equal, by the equivalent free-standing chimneys. They are sufficient to result in the crushing of the weakest, or the most severely stressed joint and to be followed, on cooling, by a complete horizontal fracture of the chimney. The effect of the supplementary shrinkage of the concrete due to the raising of the temperature contributes, of course, to a still further acceleration of this process of cracking.

Cracks affecting the concrete blocks

The results of the tests seem to indicate that the procedures for incorporating chimneys into buildings generally do not have, other things being equal, any great influence on the behaviour of the concrete blocks; concrete blocks of the same composition assembled into free-standing chimneys and fixed ones, respectively, show practically the same cracks as a result of the thermal tests, as Table II will indicate.

It should be noted, however, that this result may be due partly to the nature of the joints, which, here executed in plaster and therefore constituting weak points in the chimney masonry, have contributed, by being first to yield, to the restricting of the stresses developed in the chimney blocks due to the vertical expansion.

The effectiveness of the caulkings in the floors, also executed in plaster for the purpose of our tests, and which could also have some effect on the behaviour of the chimney blocks, on the other hand appears to have been total, according to the results of the elongation measurements.

All of these observations taken together suggest the following points:

For a given aggregate and given shape it would appear, as generally supposed, that the thermal resistance to cracking of a concrete block varies inversely as its impermeability to air.

Satisfactory impermeability can be attained in a simple manner, either by compressing very highly in the casting of a concrete of suitable proportion, or by the addition of an excess of fine aggregates to the mixture composition, or finally by application at the time of manufacture of an internal or external coating to the side faces of the chimney blocks.

The tests show that the latter solution, which in any case is hardly practical, leads to disappointing results from the standpoint of thermal strength. It should not be encouraged.

Of the other two solutions, it is undeniable that increasing the proportion of fine aggregates in the mixture results in the concretes showing greater shrinkage.

A compromise must be sought in the application of manufacturing techniques which will provide the required impermeability calling for the minimum proportion of fine aggregates for effective and strong homogeneous compact mixture.

Where the desired impermeability is attained by the use of excessively rich fine aggregates, or by the application of mortar coatings of the same type as the walls lead, for equivalent permeability values, to results that are inferior from the standpoint of thermal strength, either because of greater shrinkage, or the irregular distribution of stresses. Such solutions should therefore be avoided.

The use of concrete blocks showing the required thermal strength characteristics does not eliminate all risk of chimney cracking. In particular it seems difficult to avoid completely the development of horizontal joint cracks, which are the consequence of physical phenomena against which the only remedy is to foresee them.

When the chimneys are free to expand in the construction these cracks remain capillary and will remain the finer, the smaller the dimensional variations of the concrete block. Provided the necessary time and precautions are observed at the time of assembly and application of finishes the cracks should not reach the surface of the coatings.

However, when the chimneys are attached rigidly to the floors of the construction it appears that only such artifices as the techniques based on the principle of double independent walls make it possible to avoid in this manner the appearance of more or less localized disorders.

In summing up, these preliminary tests indicate that the behaviour in time of a chimney built of concrete blocks depends more on the intrinsic quality of the units used in its construction and the care taken in their installation.

This intrinsic quality of the units which might have depended on the principle of installation, however, has of course nothing to do with the quality of installation, which is completely foreign to it.

Under these conditions it would appear that the problem of determining the suitability of a concrete block for use in a chimney could be conceived in a much simpler form than a test on complete chimneys.

The search for a simplified test

The manner of installation, since it involves primarily the vertical compression stresses, has but little influence on the thermal resistence of the concrete blocks, the concrete of which generally has adequate compression strength.

However, the behaviour of the blocks with respect to heat is associated with all the factors which may have a direct or indirect bearing on the magnitude of the tensile stresses that develop simultaneously in the chimneys. It unquestionably depends on the inherent expansion or elastic properties of the concrete and on the shape of the blocks.

Now, the data which we possess on the particular properties of the concretes or the way in which they vary with temperature are rather meagre at the present time, and mere calculation does not enable us to predict with sufficient certainty, on the basis of data that are already inexact, the precise distribution of the stresses at various points in a casting even of simple form. A suitable selection would scarcely be possible, therefore, just now, beyond a test of the entire product.

One of the main purposes of our research, moreover, was to furnish manufacturers with an effective means of checking their production, and this check, being intended primarily to reveal such faults as inhomogeneity in the casting, could hardly be conceived otherwise than in this form.

Our study was therefore oriented towards a test of this nature. We wished to make it as simple as possible and at the same time meaningful.

In reality the temperatures attained by the concrete blocks depend on the thermal exchanges between the walls of the flues and the flue gas, on the velocity, temperature and variable chemical compositions. As the approval tests have already shown, it is difficult to realize these conditions of exchange in a test which must be above all strictly reproducible, and must not involve large, costly apparatus.

In any case the chemical effect of flue gas could scarcely be comprehended in a test of necessarily short duration, and in view of this we preferred to abandon sources of energy by combustion which are difficult to control, in favour of electricity which is much more flexible and precise.

We therefore produced a rudimentary apparatus comprising an electrical resistance wound on a refractory cylindrical core which could be introduced into the axis of the units to be tested. The first results obtained with this apparatus were encouraging and we therefore proceeded to design a more robust and practical version and ultimately produced the apparatus illustrated schematically in Fig. 6.

Technical description of the apparatus

The apparatus consists essentially of a series of 1500 watt electrical resistance elements connected in parallel and arranged vertically one above the other on a horizontal metal pedestal of dimensions suitable for the concrete blocks to be checked. The length of each resistance corresponds to the length of three superimposed blocks.

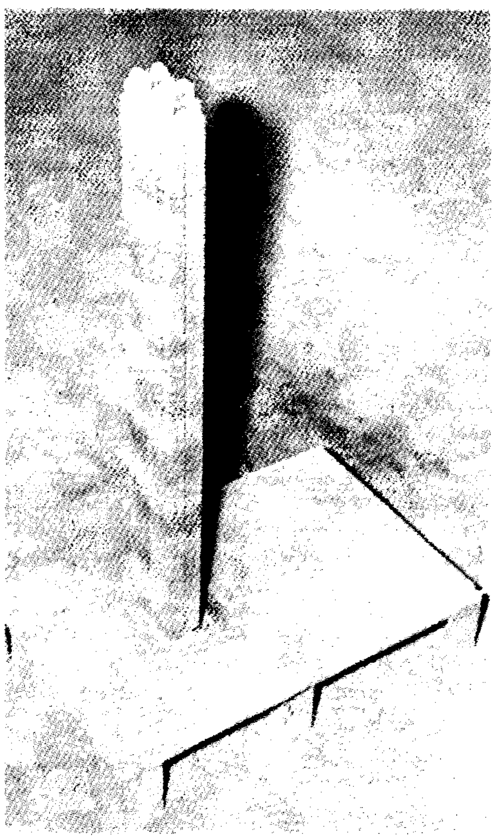
The blocks to be tested are stacked one above the other on the pedestal centred about the elements. Asbestos packings between each pair of blocks and at the top and bottom replace the usual plaster or mortar joints. These restrict the heat losses and at the same time permit easier dismantling of the blocks.

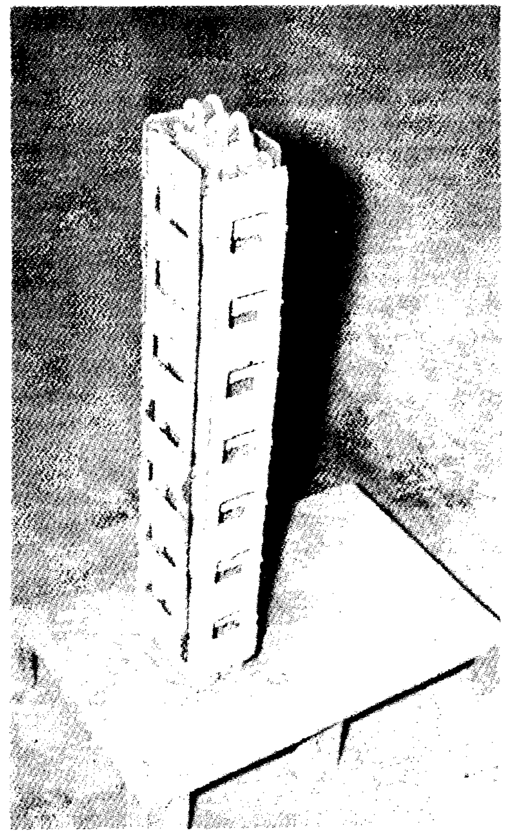
In order to avoid too severe a direct radiation of the resistances against the walls of the blocks, in the course of the tests a perforated metal sheath is introduced into the space between the electric elements and the blocks. This sheath is composed of two parallel surfaces consisting of sheet metal plates protected with asbestos and staggered in such a way as to ensure a suitable mixing of the air and an even distribution of temperatures within the space enclosed by the blocks.

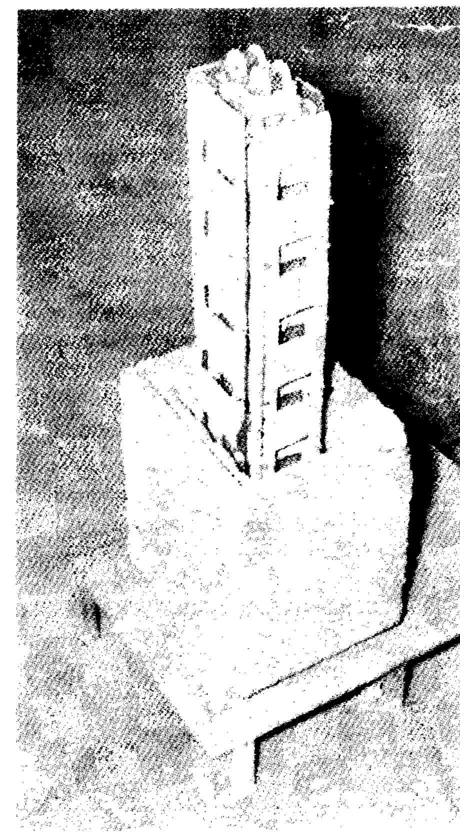
This sheath is parallel to that of the blocks and the space between the planes defining the outside envelope of the sheath and the wall of the blocks is approximately 1.5 cm. After the blocks and sheath have been set up the upper horizontal edge of the last tile is surmounted by a metal plate insulated with asbestos which thus closes off the whole volume.

Two of these apparatuses were built, one for testing blocks of 14 x 20 cm cross-section and the other for blocks of 20 x 20 cm cross-section. The total electrical consumptions of these apparatuses are 6 and 12 kw/h, respectively.

Maintenance of the desired temperature increase curve, regulated according to the readings given by an iron-constantan thermocouple connected to a recording galvanometer, is at present achieved by cutting off the feed current at an ordinary switch. It is obvious, however, that this arrangement, which requires the constant presence of an operator at the apparatus, could be replaced by an automatic control device.







Apparatus for thermal test on separate blocks

Detail of assembly of the electric heater elements on the pedestal

Assembly of the radiation protection sleeve

Mounting of first block

Analysis of utilization procedures

The magnitude of the stresses developed at any given time in a given block is directly proportional to the temperature differences existing at this time at various points in the block.

The behaviour of the concrete with respect to these stresses is itself linked to the absolute value of these temperatures, which to a certain extent determine the mechanical properties.

The test conditions are thus defined both by the value of a mean test temperature and by the rate of heating, which determines the above-mentioned differences.

Preliminary tests

A few preliminary tests were carried out at the outset in order to gauge the possibilities of the apparatus and to determine exactly the temperature gradients established in the course of operation within the test space enclosed by the blocks.

These tests showed that the temperatures prevailing at a given time at corresponding points on each fan at the same horizontal section remained sensibly the same, within a few degrees, in the immediate vicinity of the walls.

In the vertical direction, however, the temperatures decreased at a constant rate from top to bottom of the three assembled blocks, the mean temperature difference being about 60°C (108°F) for the end blocks.

However, over the height of the median block this difference does not exceed 10°C (18°F), which, for the contemplated working temperatures of the order of several hundreds of degrees, is still quite admissible.

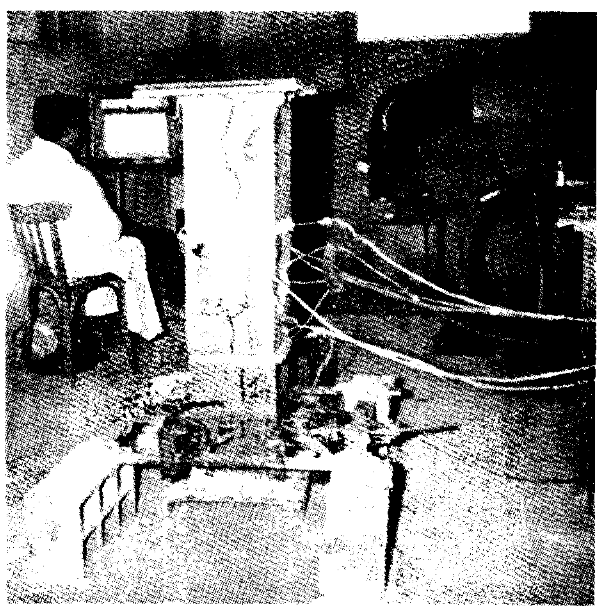
Thus the test appeared sufficiently well defined, provided one takes the precaution of checking the test temperatures at a point situated at the level of the median section of the seçond block. This block thus forms the object of the temperature check, properly speaking, the other two merely playing the part of a guard ring.

However, the vertical temperature gradient remains substantially the same, and a study of the relative behaviour of the three blocks can if necessary provide additional information on the quality level of the test specimens.

Choice of test temperatures

The results of some field tests which we undertook, reinforced by information obtained from the existing literature, seem to indicate that a temperature of 320°C (608°F) (internal wall surface temperature) would reproduce fairly well the average conditions prevailing in residential chimneys under normal service conditions.

Temperature measurements made in the course of tests according to the approval procedures show that this temperature of 320°C (608°F) is approximately that observed on the internal walls of chimneys built of blocks with the contemporary characteristics, during the 500°C (932°F) test, at approximately 1.50 m (5 ft) from the base.



Apparatus for thermal test on individual blocks.
Apparatus set up for operation

The criterion by which the thermal test for approval purposes is judged is precisely the appearance presented by the units of the chimney beyond this height of 1.50 m (5 ft). In the absence of serious indications to the contrary we decided to retain this wall temperature of 320°C (608°F) in attempting to define the procedures for the utilization of our simplified apparatus. This has the advantage of permitting a more direct comparison of the two tests.

However, the internal wall surface temperature of a chimney unit for a given number of heat input depends on the actual or wall thermal conductivity to heat flow of this unit as well as the conditions of thermal exchange with the external and especially the internal environments.

Basing the test on a constant wall surface temperature of the block would have been tantamount to subjecting the tested products to "different heat loads", and would have favoured certain products over others.

We have thus defined the temperature that it was necessary to maintain in the air of the test chamber in order to obtain the desired wall surface temperature from results obtained on 5 cm solid wall blocks, which were considered to have average thermal insulation properties. This air temperature was itself defined at a sufficient distance from the surface of the blocks so as not to be influenced by them.

Choice of the manner of raising the temperature

If we disregard the stresses due to migrations of moisture in the concrete and to the corresponding supplementary shrinkages, the horizontal stresses developed in the concrete walls at any given time are a reflection of the temperature gradients existing at this moment in the successive coaxial sections of these walls.

Before the heating apparatus is turned on, all these wall sections are at room temperature. When heating begins the temperature of the internal sections rises rapidly, while that of the outer ones increases more gradually. The temperatures throughout the walls thus evolve progressively until a steady state is reached.

When the heat source is turned on the hot internal sections expand and find themselves in a state of compression from the colder external sections, which exert a restraining effect on them. These external sections, on the other hand, show horizontal tensile stresses of an equal resultant value.

The absolute value of these stresses, of course, does not remain constant, but evolves continuously until the steady state is established.

A theoretical sutdy of COSTIC, published under the signature of M. Tirel in the issue of June 1957 of "Industries Thermiques" concludes that in the ideal case of a material assumed to be unshrinkable, the maximum compressive stresses developed in the walls of chimneys always occur, in the steady state, in the immediate vicinity of the internal walls and the maximum tensile stresses in the immediate vicinity of the external walls. This would hold regardless of whether the chimney was free to expand or was restrained in some way.

A theoretical, graphical representation of the stresses in the walls is shown in Fig. 7, taken from the cited paper.

The same study further concludes that the maximum compressive stress, in absolute value, occurs at the time when the gas temperature in the flue reaches its maximum, whereas the maximum tensile stress is reached only when the temperatures at all points in the wall have become stabilized.

When testing pozzolana concrete blocks with 5 cm solid walls we recorded the temperature variations at six points through the thickness of one of the walls. The results obtained are given by the curves of Fig. 8.

The similar shape of the time-temperature curves seems to confirm well the above conclusions, since the temperature variations and the stresses vary in the same sense. Moreover, their general course shows that the time required to attain an effective stable regime is very long.

On the basis of this information we systematically tested some blocks of the same origin or composition and under different heat input, including: (1) a slow temperature increase up to 400°C

(752°F) by 50°C (122°F) stages each maintained for about 10 minutes, followed by heating for one hour at 400°C (752°F); (2) a more rapid temperature increase up to 300°C (572°F) in 10 minutes followed by a rise from 300°C (572°F) to 400°C (752°F) in 5 minutes and then maintaining the temperature at this latter value for one hour; (3) increasing the temperature as rapidly as possible up to 400°C (752°F) and maintaining the temperature at this value for 5 hours.

The results of these tests are given in Table V.

The rates observed, which were deliberately restricted with a view to the later practical use of the apparatus, were not sufficient to bring out substantial differences from one manner of heating to another. The rapid "thermal shocks" actually influence, for all practical purposes, only the compression stresses developing near the internal surfaces of the tested units, stresses which the concrete withstands fairly well. Substantial differences in the values of the tensile stresses localized in the zones of the walls which are the last to be heated could scarcely be obtained except in tests of longer duration.

Finally, we prefer to adopt the last of the above heating rates, which is also the one enabling us to obtain in the shortest time the external temperatures of the walls which, other things being equal, are closest to the operating temperature.

The test procedure also has the advantage of reproducing on the internal surfaces of the blocks, for a control temperature of the apparatus of 475°C (888°F), temperature conditions close to those determined in the course of the field tests on chimneys, the results of which have been given elsewhere (Fig. 9).

Procedures adopted

As a result of the above considerations and the preliminary tests we adopted the following procedures for our series:

Position of temperature check point

Points situated in the median section of the 2nd block in the plane of the internal annular protecting sleeve, between a sheet metal unit and its asbestos protector.

Maximum test temperature

475°C (888°F) at the above-mentioned check point; this temperature corresponds, for a block of average properties not insulated externally, to an internal wall surface temperature of approximately 320°C (608°F), after 4 to 5 hours operation.

Curve of temperature rise

In our tests we try to reach this temperature of 475°C (888°F) in as short time as possible, i.e. in about 10 minutes. The temperature is then kept constant for at least 4 hours.

First data obtained with the apparatus

Blocks of different types, some of our manufacture and some products being examined for approval, were subjected side by side to a thermal test with the aid of the flue gas generator and with the aid of the above-described, simplified apparatus. The results of these tests are summarized in Table V.

On the whole, when slight differences observed in the curve of temperature increase are taken into account, the behaviour of similar blocks in the two tests is quite comparable.

Furthermore, certain information which could not be determined with certainty from the generator test because of the presence of the exterior plaster coating on the blocks or because of the time required for dismantling, could be verified by the electrical heater test, especially with respect to the conditions under which cracks appear and evolve in the course of the test, and with respect to the influence of the block shape.

Conditions under which cracks appear

External cracks

External cracks due to tensile stresses always appear, of course, during the heating up period. Generally they do not involve the whole thickness of the block, but are of variable depth from a few millimetres to 1 or 2 cm. These are the cracks which close in the course of cooling until, in the cooled block, they are scarcely discernible.

In certain rather rare cases the crack, a capillary one at the beginning, propagates in the course of the test until it involves the whole thickness of the wall. In this case it then closes only partially in the course of cooling.

Tests have been carried out on certain special blocks with a view to discovering whether as a result of successive heating and cooling cycles the capillary cracks noted during the first period do not become aggravated to a significant degree.

We have not discovered any great differences after these cycles either in the number or the size of these external cracks, nor, as far as we could judge, did they progress visibly within the mass of the walls from one test to the next.

Internal cracks

We were successful in establishing that the internal cracks frequently found after flue gas generator tests in the disassembled blocks all appeared during the cooling phase.

Under the effect of the rising temperature the concrete undergoes an expansion that is partially compensated by an accompanying shrinkage due to drying; one of the effects of the high temperature, moreover, is a substantial alteration of the mechanical characteristics of the concretes, particularly their tensile strength.

These shrinkages and losses of strength are at least in part irreversible phenomena and their combined action, aggravated still further by the thermal shock due to cooling supported by the internal zones of the walls brought suddenly from an environment of 300°C (572°F) to one of a few tens of degrees only, is enough to explain the appearance of these cracks.

The heating and cooling cycles applied to certain blocks have shown that unlike the damage on the external surfaces, the internal cracking is more or less aggravated from one test to the next.

Effect of the block shape on the development of cracks

The results obtained with the above-described simplified apparatus, which are parallel, as we have said, to those obtained from flue gas generator tests, confirm that the shape of the block or the design of their walls, other things being equal, plays an important part in the behaviour of the products with respect to heat.

Solid wall blocks

The test confirms that as a general rule the thicker the wall, the greater the risk of cracking. It should be noted, however, that this result obtained from blocks of wall thicknesses between 2.5 and 5 cm would not perhaps be obtained with walls that were much thicker and the external zones of which, being little affected by the heat, could retain their properties sufficiently in order to exert an effective hooping influence without damage.

The observations made further show that the cracks are approximately vertical and occur most often at the centres of two opposite block surfaces.

Special case of chimney blocks for dual flues

The test behaviour of these particular units is substantially the same as that of the solid wall units for individual chimneys. However, in our tests, here only one of the chimneys is brought to the test temperature, and this produces an uneven distribution of the stresses and displaces the cracks most frequently observed in the direction of the partition separating the two chimneys.

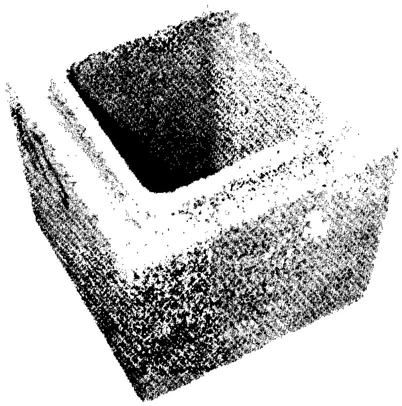
Cell wall blocks

The blocks that we tested consisted of two concrete walls 2 to 3 cm thick joined together by transverse partitions at the axis of the faces, thus enclosing four cells 1.5 to 2 cm in thickness.

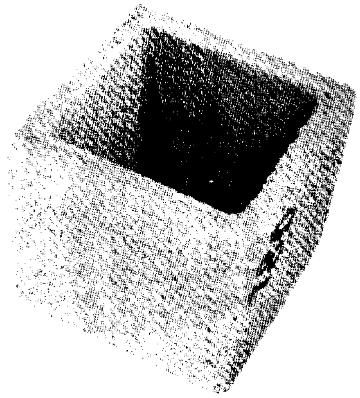
The cracks observed involved the internal face of the inside wall and sometimes the whole thickness of this wall, but never the outside wall. However, these cracks were very frequent on the internal wall.

This is due no doubt to the additional thermal insulation produced in the walls by the presence of the air gaps. Because of these gaps the internal surface, for the given test conditions, is raised

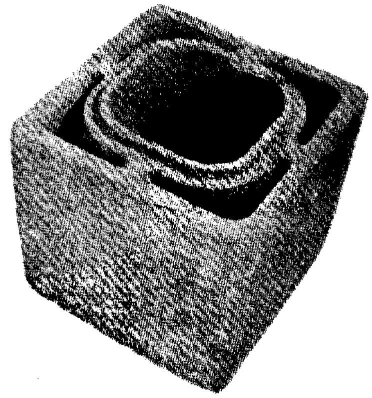
Some types of blocks submitted for testing



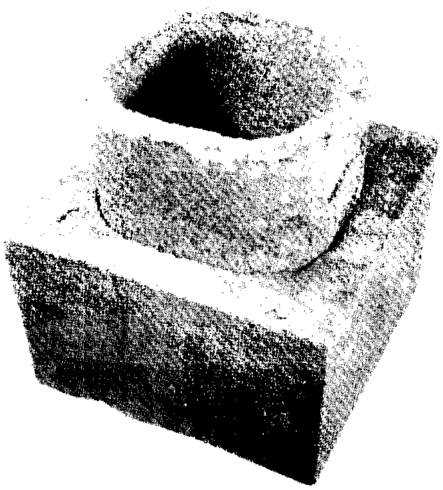
Single block with
5 cm solid walls



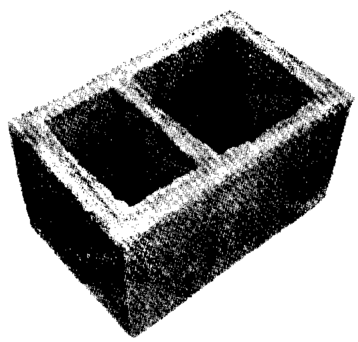
Single block with
3 cm solid walls



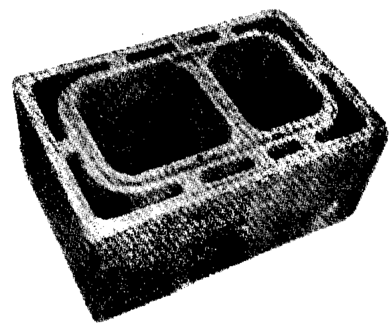
Single block with
cell walls



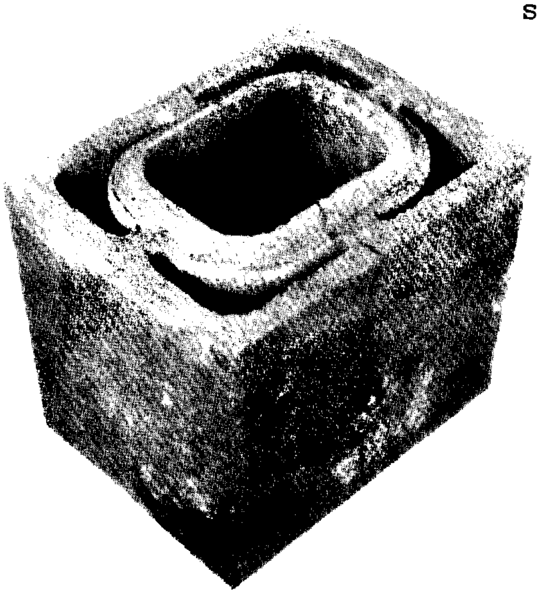
Single block with 2
independent envelopes



Compartmented
double chimney
block with 3 cm
solid walls



Compartmented double
block with cell walls



Example of the type of
rupture occurring in a
single block with cell
walls

substantially, while the mean temperature of the outside walls is lowered. Furthermore, each of these walls is subjected to temperature differences lower than those which would occur under the same conditions in comtemporary solid blocks.

Thus, the frequency of internal cracks found appears to be due mainly to shrinkages of the concrete of the internal zones, aggravated by higher wall temperatures for a given thermal load.

Finally, these cracks almost always appear in the vicinity of the transverse joining partitions, points which obviously constitute zones of maximum stress concentration.

Special case of chimney blocks for dual flues

Cell wall blocks for dual flues built on the same principle as the above blocks are also very frequently subject to cracking in the internal walls.

Furthermore, manufacturing considerations make it necessary to increase the number of joining partitions in these particular units. These partitions constitute so many fixed points which prevent deformations of the block under the effect of the expansions and thus transmit considerable str ses locally which can in turn facilitate the appearance of external cracks.

It is very difficult, under these conditions, to obtain blocks of this type that will behave in a completely satisfactory manner.

In examining the behaviour of blocks of this type and of the same composition, differing only with respect to the position of the joining partitions, it was also noted that the displacement of the partitions merely resulted in the systematic displacement of the cracks. The same composition of concrete applied to the manufacture of units for individual chimneys, however, gave completely satisfactory results in these cases.

Possibilities of application for the apparatus

A test is significant and leads to a valid classification if the conditions which it reproduces make the same demands on all the materials or units to be classified and if these demands are comparable to those of actual practice.

In order to meet this definition we tried to select thermal load conditions which would correspond to the loads actually borne by blocks under average contemporary conditions of utilization. The procedures adopted doubtless make greater demands on the blocks than those which they would have to meet under many practical circumstances. On the other hand, they are certainly less severe than other working conditions which, although accidental, are nonetheless frequent, for example ignition, open ash pit door, etc.

In any case, these thermal load conditions certainly meet the other requirement of the test, i.e. that of being easily reproducible from one test to the next.

However, in the presence of these well-defined thermal conditions the behaviour of a chimney unit still depends on the method of assembly applied to it.

We have given the reasons which led us to disregard, among the factors defining this method of assembly, those associated with the principle by which the chimney is joined to the structure. These reasons are valid, of course, only for current practice under which concrete block chimneys are installed. Thus no conclusion could be drawn without an additional study concerning the testing of products differing from these blocks, nor indeed the testing of blocks which were put into operation by methods differing from contemporary techniques.

Another factor characterizing the conditions of block assembly is the value of the thermal insulation conferred on the chimney or by walls finished with a lining.

This additional insulation, as we have said, substantially modifies the distribution of temperatures throughout the material of the chimney by improving its homogeneity, which is a favourable condition from the point of view of the tensile stresses at high temperature and therefore from the standpoint of external cracking, and in the sense of higher mean temperatures which is an unfavourable circumstance from the point of view of internal cracking.

Actually, the fact that we neglect this external thermal insulation which is always applied in practice makes the test more severe and, which is a more serious criticism for a classification test, may give some products an unfair advantage.

With a view to determining exactly the source of the error introduced by the absence of this insulation we intend to carry out a series of supplementary, parallel tests on bare blocks and blocks protected by external movable sleeves having thermal insulation properties equivalent to the coatings actually applied to blocks in practice.

The presence of these sleeves, even if they are designed independently of the blocks and are movable, cannot help but make more difficult the observation of the products during the test, and we do not think that it will be necessary to have recourse to it where the test is applied to the checking of a given production series, which can be regarded in principle as being put into operation under always comparable conditions.

Finally, the results hitherto obtained with the thermal testing apparatus on blocks have been found, broadly speaking, and under the conditions of utilization adopted, entirely parallel to those furnished by the thermal test on chimneys as defined in the rules for approval.

The material going into the construction of this apparatus is sufficiently simple and strong to find a place in the manufacturing plant itself. Moreover, the conduct of the test itself does not require any special technical skill or knowledge on the part of the user and can even be rendered practically automatic without complicating it unduly. Finally, the test itself is rapid and the small quantity of production needed in each operation facilitates the multiplication of tests at minimum expense.

For all these reasons, this simplified thermal test already appears to us to be a sure means of checking which is particularly adapted to factory and plant requirements. If well used it should constitute an effective supplementary means for the careful manufacturer to verify the uniformity of his products and their average quality.

Furthermore, thanks to its flexibility and ease of observation it could also, possibly with certain modifications in the test procedures such as the above-mentioned condition of insulating sleeves, be used as a rapid means of classifying blocks.

Research of a More Fundamental Nature

Supplementary tests

The walls of the block heated on one face only will crack when the stresses at a given point resulting from the temperatures, or more exactly from the consequent deformations, exceed the ultimate strength of the material.

The danger of cracking thus depends, for given test conditions, both on the mechanical properties of the material and on those characteristics of it which determine the magnitude of the stresses; obviously this risk decreases with an increase of the former and a decrease of the latter.

The manufacturer of concrete products wishing to go into the manufacture of chimney blocks must certainly make a choice among the materials and techniques available which will best meet these requirements, but for that he must of course possess adequate knowledge.

Particularly in the case of concretes, this knowledge is still very incomplete.

We know, for example, that heat causes the expulsion of combined moisture and thus influences the mechanical strength values of the concretes, and this leads to supplementary shrinkages which in turn produce stresses, but the precise behaviour of various binders in connection with this phenomenon or the differences in strength that may result from it are not known.

On the other hand, certain intrinsic properties which play a decisive role in the development of the stresses, for example the coefficient of expansion or that of elasticity, are not precisely defined, especially for the temperatures under consideration, and the effect which the various parameters defining the concrete may have on these is completely unknown.

Side by side with our studies of chimney blocks, therefore, with a view to attempting to fill in these gaps in our information, we have undertaken a whole series of tests to determine the main intrinsic properties which we believe must play an important part in the behaviour of the chimney.

In order to eliminate the effect of the shape of the blocks we decided to carry out these measurements on small specimens. A large number of such specimens were thus prepared, differing one from another in the kind of binder or aggregate employed, in the grain composition of this aggregate, the proportion of water present, and by the conditions of stress applied on their installation. First of all, of course, we determine the usual identifying properties of the concretes used in these specimens: shrinkage, apparent density and mechanical strength, especially tensile strength, but also properties, a knowledge of which is less often required, and which therefore are less frequently measured, such as air permeability, linear coefficient of expansion and elasticity.

Parallel tests were carried out on specimens at room temperature and identical specimens after exposure to heat under various conditions differing by age of the specimen at the time the temperature was increased, the value of this temperature, or the time during which it was applied.

The tests were also carried out, for purposes of comparison, on materials other than the concretes, materials which are also used in chimneys such as clay and asbestos cement.

These tests, which were delayed by certain difficulties in the development of the necessary test appartus, are now under way, but it is too soon to report on them here. We hope to be able to do so very shortly.

However, prior to the final development of the mentioned apparatus, we had already made some basic tests with improvised apparatus with a view to supplementing the identification tests on precast blocks which had been subjected elsewhere to full-scale tests, and to enable us to explain more fully the results obtained on these precast blocks.

Nature of tests and test procedures

These tests were carried out on specimens sawed out from the faces of blocks that had been studied elsewhere for their behaviour. The tests relate to the following properties:

Mechanical strength values at room temperature

(a) Compression strength and elasticity, measured on cubic specimens of 5 cm side taken from the faces of blocks;

(b) Tensile strength, determined from specimens cut vertically from the walls of tiles; these specimens were subjected to a pure tensile test on a Michaelis type machine;

(c) Bending strength: we also wished to attempt to determine the precise importance to be accorded certain capillary cracks frequently observed but of which it is always difficult in the time allotted for testing to estimate the depth and seriousness (Fig. 10).

For this purpose we carried out a number of comparative bending strength tests on specimens cut from various faces of the blocks, some of which, during the test in the strength apparatus, showed internal or external capillary cracks.

Supplementary shrinkage and dimensional variations

The dimensional variations of the concrete block were determined from bars 16 cm long cut from the faces of the blocks in the vertical direction. After cutting, the ends of these specimens were fitted with steel tips and their dimensional variations were determined with the aid of a deflection gauge.

To begin with the concrete of these specimens was aged sufficiently so that they could be considered to have completed their normal manufacturing shrinkage. After being measured at room temperature, which was the zero point of the measurements, the samples were placed in a space heated by electric heater elements generally to 300°C (572°F), sometimes to 450°C (842°F) or 500°C (932°F).

The length of the specimens was again determined 5 hours after having been placed in the heated space, and then again after complete cooling.

It should be mentioned here that the precision of such measurements, always carried out with the aid of the deflection gauge in the ambient air, is rather uncertain, both by reason of the errors introduced due to the heating of the measuring apparatus and because of the cooling of the specimen between the time it is taken from the furnace until it is measured.

Thus the figures given cannot claim to represent any coefficient of expansion, but simply provide approximate comparative indications with respect to the various concretes.

Comparison of the initial readings with those taken after complete cooling enabled us to determine the supplementary shrinkage experienced by the specimens in the course of heating.

Results and conclusions of tests

The results obtained are given in Tables VI to X.

Tables VII to X relate to the tests executed on blocks manufactured at the Experimental Station (the references adopted are those indicated at the top of Table II in order to characterize the composition of the concretes employed in the manufacture of these blocks; the results of Table VI relate to tests carried out on blocks being examined for approval.

On the whole these tests confirm and reproduce the results obtained on the block and chimney tests. The following remarks are in order.

Dimensional variations

The results of Table VI, which relate to blocks all examined according to the approval procedures, confirm the close relationship which appears to exist, as it was logical to assume, between the intrinsic apparent shrinkage or expansion properties of the concrete and the thermal strength of chimneys.

It may be stated that only those chimneys built of concrete showing small variations behaved satisfactorily, and that all concretes showing large supplementary shrinkage were subject to internal cracking, while those having large expansions cracked both internally and externally.

The concretes which were subject to large dimensional variations as a function of the temperature can scarcely be satisfactory unless at the same time they have rather high mechanical strength values, particularly with respect to tension, and if these properties are retained at high temperatures.

As far as possible, unstable concretes should be avoided. The results of Tables VII, VIIIa, VIIIb and IX enable us to make certain preliminary statements concerning the effect of compression, and of binder and water proportions on this instability.

(a) Effect of water content

The figures in the first part of Table VII, relating to precast blocks manufactured from concretes of the same aggregate content and assembled under identical conditions of compression (identical work applied), but differing with respect to water content, seem to indicate that there is an optimum water content from 216 to 270 litres/m^3 in the case of our tests, below and above which the supplementary shrinkage increases substantially.

It may be noted that these optimum water contents also correspond to those of the concrete showing the most favourable mechanical properties, i.e. smaller elasticity and greater strength values.

It should be added, however, that in our tests a content of 160 litres/m^3 corresponded to a concrete that was too dry, having regard to the work required to set it up, and its final density was not comparable to that of other concretes of similar composition.

Finally, it is probable that for normal water content the supplementary shrinkage, like the normal manufacturing shrinkage, varies in the same sense as the proportion of water mixture. The same applies, on the basis of the results obtained, to the apparent expansion on exposure to heat and to the absolute dimensional variations - shrinkage plus expansion.

(b) Effect of compression during casting

The results of the second part of this same Table VII relate to blocks, again all of the same aggregate content, but this time for different compression values.

These results lead to the conclusion, other things being equal, that the supplementary shrinkage decreases with the compacting of the concrete, i.e. with its density. However, the difference is relatively less than that which results simultaneously in the mechanical properties as a result of the same variable.

The figures of Table IX confirm this impression (comparison of concretes 4 and 4' and 5 and 5', of same composition but different casting compression). It is further noted from these results that the effect of an increased casting compression is to increase the apparent expansion, and the total dimensional variation of a given concrete increases with increasing density.

(c) Effect of binder content

The supplementary shrinkage of the concrete varies as a function of the binder content in the same sense as the standard manufacturing shrinkage. It increases with the latter.

On the other hand, this binder content appears to have an inverse effect on the apparent expansion, and finally the total dimensional variations do not appear to be greatly affected by this parameter (Table VIIIa and VIIIb).

These conclusions appear somewhat in contradiction with the results obtained from the chimney tests, which indicated regularly increasing elongations with increasing density, whether the latter resulted from an increase in the compaction pressure or in the proportion of fine aggregates.

However, in these initial measurements the concretes compared differed more in the proportion of inert fine aggregates than in the fine aggregates furnished by the binder. These inert fine aggregates, already coarser, undoubtedly affect the shrinkage less than the binder itself, and the measured apparent expansion, depending partly on the shrinkage in the course of heating, may be influenced accordingly.

The results obtained from specimens cut from precast blocks identical with those used for the chimney tests (Table IX) do fall neatly within the same classification as the elongations of the corresponding elongations (Table I).

All the results confirm the importance of choosing concretes that give minimum shrinkage or expansion with temperature for the manufacture of blocks.

It would seem that shrinkage has a greater effect than expansion. While there has been no exact confirmation of this point it appeared to us as though, other things being equal, a shrinkage of given amplitude could result in a crack, whereas an expansion of the same magnitude was borne without damage.

This could be very easily explained, moreover, by the fact that the deterioration of mechanical properties of the concrete is clearly the greater, the higher the temperature to which it has been raised. This is precisely what occurs in the vicinity of the internal faces.

Although we still have no exact data on the relationship which must exist between the mechanical strength of the concrete and its dimensional characteristics, it can nevertheless be stated that the ideal composition to be adopted in all cases will be that which will lead to the smallest shrinkages while at the same time guaranteeing adequate permeability and high mechanical strength values, even at the cost of a slight increase in expansion.

Such a composition, for a given aggregate and binder, is that which, with a percentage of fine aggregates, and particularly the smallest possible proportion of cement, enables us to obtain just the right degree of permeability. This requires a careful initial study of the proportions of water and the casting conditions.

With respect to this absolutely essential care to be applied to the casting operation, the results given in the above-mentioned table are particularly significant. They show, in fact, that even a slight defect in the adjustment of the casting machine is enough to result in heterogeneity of the concrete, which is reflected in differences of the properties of the different precast blocks of the same order of magnitude as that resulting from the parameters being studied.

<u>Effect of cracks on the mechanical strength of the walls</u>

The results of the measurements carried out with a view to defining the effect of cracks on the mechanical strength of the walls have been assembled in Table X.

For each precast block the specimens consisted of the four complete faces cut out by sawing in the vicinity of the angles defining the contour of the internal section; these samples were arranged on two horizontal supports 15 cm apart parallel to their major axis and were loaded mid way along this major axis; the surface involved by the load was the same as that corresponding to the interior of the block.

These tests, although rudimentary, show that the finest internal capillary crack, scarcely visible during the observation of the block and which might be thought to involve only the surface cement grouting originating from the casting, actually goes to a considerable depth in the wall and reduces its cohesion by at least 50%.

When it is remembered that in reality concrete blocks undergo heating and cooling cycles, which, as we have seen, can aggravate disorders already more serious than might be supposed after the first heating, these innocuous appearing capillary cracks cannot be left out of account in determining the quality of the product.

General Conclusion

It is still too soon, as we have said, to draw up general rules from these studies or particular, exact mixtures. Even now, however, it can be stated that in any case such rules or mixtures can have no real practical consequence unless their application is accompanied by continuous inspection.

The tests certainly confirm that it is possible to design and manufacture concrete blocks affording the required guarantees of strength and permanence. Comparison tests carried out in the course of our studies on various clay blocks chosen at random from commercial sources, indicate that a high-quality concrete block has every chance, if correctly assembled, of behaving in service at least as well as the best traditional blocks.

However, the same tests indicate that this high-quality concrete block cannot simply be a product of line manufacture comparable to that of other structural units such as masonry units or slabs.

The manufacture of concrete blocks demands from the start a careful choice of concrete constituents, and then careful pouring and exact observation of proportioning, casting and storing conditions. Such requirements, of course, could just as well be enunciated for any sort of manufacture, but in this case they demand even more rigorous observation on the part of the manufacturer, and this is unattainable, in our opinion, except at the cost of continuous, severe checking.

In this regard the test apparatus described here, supplemented by classical concrete checking techniques, ought to put a valuable aid in the hands of the manufacturer by enabling him to verify the homogeneity of his product and giving him a means of improving its properties still further, and in addition we hope that the research now being conducted at the Experimental Station on the intrinsic properties of these materials will furnish the data necessary for choosing the most appropriate constituents.

However, these manufacturing imperatives and the quality which must result from them are not the only necessary conditions for the good behaviour of the chimney, for this behaviour still depends at least to an equal extent on the care applied to the assembling of the units.

The assembly conditions were not the principal subject of our study, but it appeared essential here to emphasize their importance, especially the absolute necessity of applying extreme care to the execution of joints and coatings.

This is all the more essential in the particular case of concrete blocks in view of the fact that these products are subject to relative dimensional instability as a function of the moisture content, which can produce certain disorders even before the chimney has been put into service. These disorders are less frequent with the traditional clay materials.

In reality, the installation of chimneys, which is sometimes subcontracted by the builder, is too often carried out without any control or inspection in defiance of the most elementary rules of good construction.

There would be no point, of course, in putting high-quality products on the market if this other aspect of the problem were not also taken into consideration.

In the course of this paper we have tried to draw such conclusions as appear on the plane of practice to flow logically from the results of the tests, whether it is a question of design, manufacture or assembly.

In fact, these conclusions are almost all directly or indirectly the consequence of a need to combine conditions that can guarantee satisfactory behaviour of joints and critical points in the structure.

From this point of view one may well ask whether it would not already be preferable to build fewer of these chimneys, most of which will never be of any use, and then to demand on the other hand that they shall be better constructed. Following up this idea, it would appear logical to attempt to restrict the number of joints in these chimneys and then the execution of the joints could more easily become the object of the necessary particular attention.

There is certainly room in this field for solutions requiring units of large dimension, which would correspond, moreover, to a general tendency in the evolution of the building industry, and of which even now certain manufacturers are making studies.

<u>Table I</u> - Tests of normal operation

PRELIMINARY TESTS OF ACTUAL OPERATION
Temperature of surrounding air: external 13 - 18°C, internal 16 - 20°C

Type of stove	Length of connecting pipe	Fuel employed	Draught conditions	Rate of gas flow in the flue (standardized to 0°C, 760 mm)	Temp. of gases meas. at base of the flue	Temp. of flue wall (5 cm blocks of pozzolana concrete coated with 2 cm plaster) meas. at level of 1st block	
						Internal face	External face
Continuous burning Indirect draught	1.20 m	Semi-bituminous coal	Max. draught from closed ash pit door	65 m^3/h	245°C	130°C	40°C
	1.20 m	Semi-bituminous coal	Max. draught from open ash pit door	90 m^3/h	285°C	165°C	50°C
	1.20 m	Oak	Max. draught from closed ash pit door	82 m^3/h	300°C	185°C	55°C
	1.20 m	Oak	Max. draught from open ash pit door	104 m^3/h	350°C	220°C	60°C
Continuous burning Direct draught	1 m	Semi-bituminous coal	Max. draught from closed ash pit door	28 m^3/h	400°C	130°C	40°C
	1 m	Semi-bituminous coal	Max. draught from open ash pit door	34 m^3/h	400°C	140°C	40°C
	1 m	Oak	Max. draught from closed ash pit door	83 m^3/h	675°C After 80 min. operation	320°C After 80 min. operation	80°C
	1 m	Oak	Max. draught from open ash pit door	104 m^3/h	750°C After 80 min. operation	395°C After 80 min. operation	90°C
18,000 cal. oil stove	0.30 m	Fuel oil	Maximum rate	100 m^3/h	450°C	280°C	70°C

TABLE II

TESTS ON CHIMNEYS ASSEMBLED FROM CONCRETE BLOCKS MANUFACTURED AT THE EXPERIMENTAL STATION
(EXPANSION AND THERMAL STRENGTH)

REFERENCES	DESCRIPTION OF CHIMNEYS							RESULTS OF TESTS								
	CONCRETE			BLOCKS			METHOD OF PUTTING FLUE INTO OPERATION	AIR PERMEABILITY OF CHIMNEY (BEFORE TEST)	MAXIMUM TEMPERATURE OF EXTERNAL WALLS (400°C)	APPARENT VERTICAL EXPANSION OF CHIMNEYS (IN MM)(1)		CRACKS OBSERVED				
												DURING TEST		AFTER COOLING		
	COMPOSITION OF CONCRETE (TO THE M³ IN PLACE)	MODE OF CLAMPING	APPARENT DENSITY	TYPE	TYPE OF COATING	AIR PERMEABILITY (COEFF. K)				AT 400°C	AT 500°C	JOINTS	BLOCKS	JOINTS	BLOCKS EXTERNAL FACES	BLOCKS INTERNAL FACES
1	POZZOLANA 2.5/7 MM 190 KG CEMENT CPB 230/315 (SIEVE ANALYSIS CURVE NO.1)	STANDARD	1.23	SINGLE 5 CM BLOCK WITH SOLID WALLS INTERIOR SECTION 20 x 20 CM	NONE	4 520	DETACHED	NOT MEASURED	30°	0,4 0,5 0,2	0,6 0,5 0,3	NONE	NONE	NONE	NONE	NONE
							ATTACHED	NOT MEASURED	30°	0,1 0 0	0,1 0,1 0,1	1 CRACK AT 11th JOINT	NONE	11th JOINT	NONE	1st AND 3rd BLOCK
					INTERNAL COATING WITH CEMENT LIME MORTAR	115	DETACHED	125	65°	2 0,8 0,2	2,5 2,0 0,7	10th AND 11th JOINTS	UP TO THE 9th BLOCK	NONE	1st, 2nd AND 6th BLOCK	FROM 1st TO 9th BLOCK
					EXTERNAL COATING WITH CEMENT LIME MORTAR	31	DETACHED	88	65°	1 0.5 0,2	1,1 0,9 0,4	1st, 3rd, 11th AND 12th JOINTS	NONE	NONE	NONE	3rd, 4th AND 6th BLOCKS
2	POZZOLANA 0/7 MM 195 KG CEMENT CPB 250/315 (SIEVE ANALYSIS CURVE NO.2)	STANDARD	1.42		NONE	2 720	ATTACHED	NOT MEASURED	30°	0,3 0,3 0,2	0,2 0 0,1	NONE	NONE	FROM 1st to 8th JOINT	NONE	NONE
							DETACHED	NOT MEASURED	30°	0,9 0,6 0,3	1,5 1,2 0,5(2)	2nd, 3rd, 4th AND 8th JOINTS	NONE	NONE	NONE	FROM 1st TO 7th BLOCK
							DETACHED (3)	NOT MEASURED	30°	0,8 0,5 0,4	1,1 0,8 0,6	NONE	NONE	NONE	NONE	...
					EXTERNAL COATING WITH CEMENT LIME MORTAR	52	DETACHED (3)	75	65°	1.1 1.0 0.6	1,9 1,1 0,5	1st, 2nd, 3rd, 6th, 7th AND 8th JOINTS	1st, 2nd AND 3rd BLOCKS	NONE	NONE	—
							ATTACHED (3)	90	75°	0,1 0,1 0,3	0,4 0,2 0,3	1st, 2nd AND 3rd JOINTS	1st, 2nd AND 3rd BLOCKS	11th JOINT	NONE	1st, 2nd, 4th, 6th, 9th, 10th, 11th, 12th AND 13th BLOCKS
					INTERNAL COATING WITH CEMENT LIME MORTAR	110	DETACHED (4)	115	75°	1,3 1,2 0,2	2,1 1,8 0,4	1st, 2nd, 3rd, 7th, 8th, 9th, 10th AND 11th JOINTS	1st, 2nd, 3rd AND 4th BLOCKS	NONE	NONE	—
							ATTACHED (4)	135	65°	0,3 0,2 0,5	0,4 0.2 0,4	6th, 10th AND 11th JOINTS	1st, 2nd, 3rd, 4th and 6th BLOCKS	8th JOINT	NONE	FIRST 13 BLOCKS
3	1 VOL. POZZOLANA 0/7 MM 1 VOL. POZZOLANA 0/4 MM 50 LITRES FLY ASHES 270 KG CEMENT CPB 250/315 (SIEVE ANALYSIS CURVE NO.3)	STANDARD	1.52		NONE	1 750	DETACHED	1 780	45°	0,9 0,5 0.2	1,4 0,8 0,5	1st, 2nd, 8th, 10th, 11th AND 12th JOINTS	NONE	NONE	NONE	1st BLOCK
							ATTACHED	1 820	45°	0,1 0 0,1	0,2 0 0	10th JOINT	NONE	9th AND 10th JOINTS	NONE	NONE
					INTERNAL COATING WITH CEMENT LIME MORTAR	32	DETACHED	86	75°	1,7 1,5 0,5	2,0 2,0 0,4	UP TO THE 11th JOINT	FROM 1st to 7th AND 9th AND 10th BLOCKS	NONE	3rd, 4th, 5th AND 6th BLOCKS	FROM 1st to 20th AND 13th BLOCK
					EXTERNAL COATING WITH CEMENT LIME MORTAR	24	DETACHED	95	80°	0,9 0,9 0,1	1,6 1,0 0,2	1st, 2nd, 3rd, AND 11th JOINTS	1st, 2nd AND 3rd BLOCKS	NONE	NONE	FROM 1st to 5th BLOCK
4	4 VOL. POZZOLANA 0/7 MM 2 VOL. POZZOLANA 0/4 MM 110 LITRES FLY ASHES 225 KG CEMENT CPB 250/315 (SIEVE ANALYSIS CURVE NO.4)	STANDARD	1.65		NONE	320	DETACHED	390	70°	1,5 1,0 0,6	1,9 1,2 0,9	1st, 2nd, 3rd, 7th, 8th, 10th, AND 11th JOINTS	1st, 2nd, 3rd, 7th AND 8th BLOCKS	NONE	NONE	FROM 1st to 10th BLOCK
5	3 VOL. POZZOLANA 0/7 MM 4 VOL. POZZOLANA 0/4 MM 60 LITRES FLY ASHES 200 KG CEMENT CPB 250/315 (SIEVE ANALYSIS CURVE NO.5)	STANDARD	1.63		NONE	380	DETACHED	450	75°	1,4 1,1 0,5	1,9 1,3 1,0	1st, 2nd, 3rd, AND 8th JOINTS	NONE	NONE	NONE	FROM 1st to 6th BLOCK
6	POZZOLANA 0/4 MM 225 KG CEMENT CPB 250/315 (SIEVE ANALYSIS CURVE NO.6)	STANDARD	1,77	SINGLE 5 CM BLOCK WITH SOLID WALLS INTERIOR SECTION 20 x 20 CM	NONE	500	DETACHED	550	70°	2,3 1,7 0,7	2,3 1,5 0,7	FROM 1st to 3rd AND FROM 6th to 11th JOINT	1st, 2nd, 3rd AND 4th BLOCKS	NONE	NONE	FROM 1st to 5th BLOCK
							DETACHED	490	75°	2 1,2 0,6	2,5(2) 2,0 0,3	FROM 1st to 12th JOINT	FROM 1st to 7th BLOCK	NONE	NONE	FROM 1st to 10th BLOCK
							ATTACHED	570	70°	0,8 0,4 0,2	0,8 0,4 0,8	2nd, 3rd, 4th AND 5th JOINTS	FROM 1st to 10th BLOCK	2nd JOINT	NONE	FROM 1st to 11th BLOCK
2	COMPOSITION NO. 2	SEVERE	1.57		NONE	1 850	DETACHED	—	45°	0,8 0,4 0,2	1,4 1,0 0,6	1st AND 11th JOINTS	NONE	NONE	NONE	1st AND 2nd BLOCKS
					EXTERNAL COATING WITH CEMENT LIME MORTAR	14	DETACHED	23	70°	1,5 1,0 0,5	1,5 1,0 0,5	1st, 2nd, 8th, 9th AND 10th JOINTS	FROM 1st to 13th BLOCK	NONE	FROM 1st to 7th BLOCK	FROM 1st to 13th BLOCK
					INTERNAL COATING WITH CEMENT LIME MORTAR	52	DETACHED	74°	70°	1,5 1,0 0.5	1,9 1,1 0,5	1st, 2nd, 3rd, 6th, 8th, 9th, AND 10th JOINTS	FROM 1st to 11th BLOCK	NONE	FROM 1st to 6th BLOCK	FROM 1st to 11th BLOCK
					EXTERNAL COATING WITH CEMENT LIME MORTAR	35	DETACHED	62	75°	1,5 1,0 0,2	2,0 1,5 0,8	FROM 1st to 11th JOINT	FROM 1st to 6th BLOCK	NONE	3rd, 4th AND 5th BLOCKS	FROM 1st to 12th BLOCK
4	COMPOSITION NO. 4	SEVERE	1,74		NONE	8	DETACHED	30	75°	2,0 1,2 0,2	2,2 1,2 0,5	FROM 1st to 11th JOINT	FROM 1st to 12th BLOCK	NONE	NONE	FROM 1st to 10th BLOCK
5	COMPOSITION NO. 5	SEVERE	1,74		NONE	9	DETACHED	20	80°	1,9 0,9 0,8	2,1 1,1 0,6	FROM 1st to 11th JOINT	1st, 2nd AND 3rd BLOCKS	NONE	NONE	FROM 1st to 9th BLOCK

1. The figures indicated in the column under the heading "Apparent vertical expansion of chimneys" correspond from bottom to top respectively to measurements made at 0.40, 1.70 and 3.00 m from the base of the chimney.
2. Testing up to 700°C. 3. Three successive tests on the same chimney. 4. Two successive tests on the same chimney.

Table III

Test carried out on chimneys assembled from concrete blocks submitted for approval (permeability and thermal tests)

Reference	DESCRIPTION OF CHIMNEYS				DESCRIPTION OF RESULTS					
	Kind of concrete	Type of block (1)	Air permeability coefficient (uncoated block) K	Chimney installation	Air permeability chimney (coefficient K)			Cracks observed before and after thermal test		
					Before thermal test	After thermal test		Joints		Precast blocks (after test)
						Hot chimney	After cooling	Before test	After test	
A	Chamotte	u.g.a.	0.3	Chimneys secured in floor 2 cm plaster coating	5.3	5.5	6.6	No cracked joint	1 cracked joint	No crack
B	Chamotte	i.p.p.5	1.1		21	20	21	2 cracked joints	1 cracked joint	Int. cracks on 1st and 2nd block
C	Chamotte	u.p.p.3	2		25	18	24.5	No cracked joint	13 cracked joints	No crack
D	Pozzolana and clay screenings	u.p.p.3	4.3		27	24	28	No cracked joint	1 cracked joint	Int. cracks on 1st block
E	Chamotte	i.g.a.	8.5		10	7.5	10.5	2 cracked joints	No cracked joint	Int. cracks on 1st and 2nd blocks
F	Chamotte	u.p.p.3	12		11.5	11	11	1 cracked joint	No cracked joint	Int. and ext. cracks on the 1st and 2nd blocks. Int. cracks on 3rd block
G	Chamotte	u.g.a.	20	Chimneys secured in floor 2 cm plaster coating	27	27	23	1 cracked joint	No cracked joint	Int. cracks on 1st and 2nd blocks
H	Chamotte	i.g.a.	21.5		11	11	12	No cracked joint	6 cracked joints	Int. cracks on 1st, 2nd, 3rd and 4th blocks
I	Pozzolana	i.p.p.5	24		28	25	30	2 cracked joints	3 cracked joints	Int. and ext. cracks on 1st and 2nd blocks
J	Pozzolana	i.p.p.5	110		14	16	13	3 cracked joints	8 cracked joints	Int. and ext. cracks on 1st block, int. cracks on 2nd, 3rd, 4th and 5th blocks
K	Foamed slag	i.g.a.	270		100	120	105	2 cracked joints	No cracked joint	Int. and ext. cracks on 1st to 24th block
L	Pozzolana	i.p.p.5	400		120	.5		1 cracked joint	No cracked joint	Int. cracks on 1st and 2nd blocks

(1) u.g.a. = single block with cell walls
i.g.a. = single block with air sleeve
u.p.p.3= single block with 3 cm solid walls
i.p.p.3 or 5= single block with 3 or 5 cm solid walls

Table IV

Comparative permeability figures of uncoated and plaster coated blocks (permeability coefficient K)

Uncoated blocks	Blocks with 1 cm plaster coat	Blocks with 2 cm plaster coat
24	1.0	
30	2.0	
37	0.5	
38	1.0	
65	3.0	
120	1.5	
125	1.0	
290	1.5	
310	1.0	
350	1.0	
400	1.0	
1,320	4.0	< 1.0
1,360	5.0	< 1.0
1,800	1.0	
1,920	3.5	< 1.0
2,000	4.5	< 1.0
2,440	1.5	< 1.0
2,460	2.5	< 1.0
2,620	5.0	< 1.0
3,300	3.0	< 1.0
3,800	3.5	< 1.0
3,800	2.5	< 1.0
5,000	4.0	< 1.0
10,000	3.0	< 1.0

<u>Table Va</u> - Comparison of thermal test results on chimneys and individual blocks

Block symbols	Block type (1)	Kind of concrete	Thermal tests	
			On chimneys (2) (approval test procedures)	On individual blocks (rapid heating up cycles to 300 and then 400°C)
			Cracks observed on blocks after disassembling of chimney	Cracks observed on the 2nd unit after cooling
A	u.g.a.	Chamotte	None	None
B	i.p.p.5	Chamotte	Int. cracks 1st and 2nd	None
C	u.p.p.3	Chamotte	None	None
D	u.p.p.3	Pozzolana and clay screenings	Int. cracks	None
E	i.g.a.	Chamotte	Int. cracks 1st and 2nd	None
F	u.p.p.3	Chamotte	Int. and ext. cracks, 1st and 2nd. Int. cracks 3rd	None
G	u.g.a.	Chamotte	Int. and ext. cracks 1st and 2nd	None
H	i.g.a.	Chamotte	Int. cracks 1st, 2nd, 3rd, 4th	None
I	i.p.p.5	Pozzolana	Int. and ext. cracks 1st and 2nd	None
V	i.g.a.	Pozzolana	Int. cracks 2nd and 3rd	None
W	u.p.p.3	Pozzolana	Int. and ext. cracks 1st. Int. cracks 2nd, 3rd, 4th, 7th, 10th, 11th	Internal cracks

(1) and (2): See footnotes after Table Vb.

Table Vb - Comparison of thermal tests on individual blocks depending on the curve of temperature rise adopted

Block symbols	Block type (1)	Kind of concrete	Thermal tests (on individual blocks) — Cracks observed on the 2nd unit after complete cooling	
			Rapid cycle of temp. increase to 300° and 400°C	Temp. rise cycle by stages to 150°-200°-250°-300°- and 400°C
H	i.g.a.	Chamotte	None	None
A	u.g.a.	Chamotte	None	None
U	u.g.a.	Chamotte	1 int. crack	1 int. and ext. crack
M	u.g.a.	Pozzolana and clay screenings	1 int. crack	1 int. and ext. crack
N	u.g.a.	Pozzolana and clay screenings	1 int. crack	1 int. crack
C	u.p.p.3	Chamotte	None	None
O	u.p.p.3	Pozzolana	1 int. crack	1 int. crack
P	u.p.p.3	Pozzolana	None	None
Q	i.p.p.5	Pozzolana	1 int. crack	1 int. and ext. crack
R	i.p.p.5	Foamed slag	1 int. and ext. crack	1 int. and ext. crack
S	i.p.p.5	Pozzolana	1 int. crack	1 int. crack
T	u.p.p.3	Pozzolana	None	None

(1) u.p.p.3 = single block with 3 cm solid walls
u.g.a. = single block with cell walls
i.g.a. = single block with air sleeve
i.p.p.3 or 5 = single block with 3 or 5 cm solid walls

(2) In the approval test only cracks above 1.50 cm from the base of the chimney, i.e. from the 6th (blocks of 33 cm) or 8th block (blocks of 25 cm) were considered.

Table VI

Behaviour of blocks in the presence of heat, as a function of dimensional variations and mechanical properties of the concretes employed

Kind of aggregate	Block type	Specimens kept at 150°C for 5 hrs		Specimens kept at 300°C for 5 hrs		Specimens kept at 500°C for 5 hrs		Result of thermal test	Mechanical properties of concrete (prior to test)		
		Appar. expansion mm/m	Supplementary shrinkage* mm/m	Appar. expansion mm/m	Supplementary shrinkage* mm/m	Appar. expansion mm/m	Supplementary shrinkage* mm/m		Settlement under compression 80 kg/cm² mm/m	Compress. strength kg/cm²	Tensile strength kg/cm²
Slag and cuttings	5 cm solid walls	0.72	-0.22	2.09	-0.65	8.43	-0.72	Int. and ext. cracks	3.2	106	9.1
Clay screenings	5 cm solid walls	0.93	-0.15	2.56	-0.43	3.53	-0.78	Ditto	3.9	255	18.3
Pozzolana	5 cm solid walls	0.53	-0.37	1.03	-1.15	3.5	-2.12	Int. cracks	4.12	225	17.5
Pozzolana	3 cm solid walls	0.65	-0.15	1.37	-0.46	2.75	-0.28	None	1.75	269	14.8
Pozzolana	3 cm solid walls	0.43	-0.15	1.06	-0.59	1.22	-1.28	None	1.50	360	16.7
Pozzolana	3 cm solid walls	1.62	-0.31	1.18	-0.78	5.40	-1.56	Int. cracks	1.91	353	18.4
Clay screenings	3 cm solid walls	0.47	-0.34	1.87	-0.55	3.52	-1.02	None	2.12	626	22.1
Chamotte	3 cm solid walls	0.47	-0.25	1.15	-0.70	2.40	-0.81	None	1.91	288	15.7
Chamotte	With air sleeve	0.56	-0.56	1.15	-0.78	3.03	-1.34	None	1.50	373	—
Schist	With air sleeve	0.5	-0.37	0.59	-1.65	1.06	-2.06	Int. cracks	2.2	507	21.8
Pozzolana	With air sleeve	0.43	-0.25	0.59	-1.00	1.40	-1.34	None	2.3	210	8.9

* After cooling and in relation to initial dimensions

Table VII

Effect of quantity of water employed and casting compression on the dimensional variations and mechanical characteristics of the concrete (tests at 300°C)

Description of concrete: Quantity of aggregates	Description of concrete: Quantity of water l/m³ shaken down	Description of concrete: Duration of vibration in sec	Block symbols	Appar. expansion (300°C for 5 hrs) mm/m	Supplementary shrinkage 300°C for 5 hrs mm/m		Total dimensional change (expansion + shrinkage) mm/m		Mechanical characteristics of concrete (before test): Settlement under compression 80 kg/cm² mm/m		Compress. strength kg/cm²		Tensile strength kg/cm²
Identical to that of series 3	160	50 sec.	a	1.22	0.69		1.91						Not measured
			c	1.34	0.66	0.67	2.00	1.97	2.2		114		
			d	1.34	0.66		2.00						
	216	50 sec.	a	1.44	0.59		2.03						
			c	1.56	0.47	0.53	2.03	2.05	1.8		149		
			d	1.56	0.53		2.09						
	270	50 sec.	a	1.88	0.53		2.41						
			c	1.72	0.53	0.53	2.25	2.32	1.7		168		
			d	1.78	0.52		2.30						
	340	50 sec.	a	1.82	0.59		2.41						
			c	1.79	0.66	0.62	2.45	2.40	2.2		128		
			d	1.72	0.62		2.34						
Identical to that of series 3	160	25 sec.	a	Not measured	0.78		Not measured		4.8		38		2.9
			b		0.75				3.6		81		
			c		0.78	0.77			3.2	4	73	67.5	5.2
			d		0.78				4.4		78		
		50 sec.	a		0.59				4.4		94		3.4
			b		0.81				2.4		69		
			c		0.72	0.70			2.8	3.3	108	89	8.0
			d		0.69				3.6		85		
		75 sec.	a		0.56				3.2		110		7.2
			b		0.62				3.0		90		
			c		0.72	0.66			2.0	2.5	158	117	7.6
			d		0.75				2.0		109		
	216	25 sec.	a		0.78				2.4		144		8.7
			b		0.72				3.4		92		
			c		0.62	0.72			3.2	3	95	100	14.5
			d		0.78				3.2		63		
		50 sec.	a		0.59				2.4		185		14.8
			b		0.59				2.0		119		
			c		0.59	0.62			1.8	2.1	114	145	14.1
			d		0.69				2.0		162		
		75 sec.	a		0.59				2.4		174		14.8
			b		0.59				2.2		150		
			c		0.56	0.61			1.4	2.2	165	156	19.3
			d		0.59				2.6		142		

Table VIIIa

Effect of quantity of cement employed on the dimensional variations and properties of the concretes
(tests at 300°C and 500°C)

Description of concrete: Constituents (aggregate + water)	Description of concrete: Cement shaken down kg/m³	Description of concrete: Duration of vibration in sec.	Block symbols	Appar. expansion (300°C for 5 hrs) mm/m	Supplementary shrinkage 300°C for 5 hrs and cooling mm/m		Total dimensional change (expansion + shrinkage) mm/m		Mechanical properties of concrete (before test): Settlement under compression 80 kg/cm² mm/m	Mechanical properties of concrete (before test): Compress. strength kg/cm²	Mechanical properties of concrete (before test): Tensile strength kg/cm²
Identical to that of series 5	190	50 sec.	a	1.78	0.50	0.49	2.28	2.49	3.0	80	Not measured
			c	2.04	0.53		2.57				
			d	2.18	0.44		2.62				
	270	50 sec.	a	2.02	0.50	0.52	2.52	2.51	1.8	155	
			c	1.97	0.53		2.50				
			d	1.99	0.52		2.51				
	340	50 sec.	a	1.60	0.62	0.62	2.22	2.23	1.2	265	
			c	1.63	0.62		2.25				
			d	1.61	0.62		2.23				

Table VIIIb

Description of concrete: Constituents (aggregate + water)	Description of concrete: Cement shaken down kg/m³	Description of concrete: Duration of vibration in sec.	Block symbols	Appar. expansion (300°C for 5 hrs) mm/m	Supplementary shrinkage 300°C for 5 hrs and cooling mm/m		Total dimensional change (expansion + shrinkage) mm/m		Mechanical properties of concrete (before test): Settlement under compression 80 kg/cm² mm/m	Mechanical properties of concrete (before test): Compress. strength kg/cm²	Mechanical properties of concrete (before test): Tensile strength kg/cm²
Identical to that of series 5	190	50 sec.	b	3.25	0.47	0.48	3.71	3.77	3.4	Not measured	6.5
			d	3.34	0.50		3.84				
	270	50 sec.	e	3.12	0.72	0.66	3.84	3.75	1.7		12.5
			d	3.06	0.60		3.66				
	340	50 sec.	b	2.66	1.00	1.02	3.66	3.64	1.3		17
			d	2.58	1.04		3.62				

Table IX

Inherent characteristics of concrete blocks manufactured at the Experimental Station and subjected to thermal tests on chimneys

Concrete symbol	Specimens brought to a temp. of 300°C for 5 hrs			Mechanical properties of concrete (before test)		
	Apparent expansion mm/m	Supplementary shrinkage mm/m	Total dimensional change mm/m	Settlement under compression 80 kg/cm² mm/m	Compress. strength kg/cm²	Tensile strength kg/cm²
1	1.25	-0.53	1.78	5	80	5
2	1.56	-0.50	2.06	6	75	5
3	1.45	-0.70	2.15	1.8	320	17.5
4	1.45	-0.70	2.15	2.0	250	15.5
4'	1.63	-0.64	2.27	1.9	290	16.5
5	1.44	-0.65	2.09	2.2	160	11.9
5'	1.65	-0.60	2.25	2.1	190	14.5
6	1.59	-0.69	2.28	1.8	300	16.5
Gravillon concrete	2.5	+0.15	2.75	1.5	340	19

Table X

Effect of cracks on the mechanical properties of walls of blocks

Block type	Designation		State of face tested (1)	Apparent depth of crack cm	Breaking load in simple bending (Distance between supports: 15 cm)	
	Block symbol	Face no.			Cracked faces kg	Uncracked faces kg
Individual block with solid walls 5 cm thick Section 20 x 20 cm pozzolana concrete	7	1	I.E.	-	45	-
		2	N.F.	0	-	350
		3	I.E.	-	50	-
		4	N.F.	0	-	270
	8	1	I.	4	145	-
		2	N.F.	0	-	490
		3	I.	4	170	-
		4	N.F.	0	-	470
		1	N.F.	0	-	430
		2	I.E.	-	50	-
		3	N.F.	0	-	515
		4	I.E.	-	110	-
		1	N.F.	0	-	450
		2	I.	4	130	-
		3	N.F.	0	-	415
		4	I.	4	100	-
	9	1	I.	3	55	-
		2	N.F.	0	-	180
		3	I.	3	75	-
		4	N.F.	0	-	240
	10	1	I.	2	180	-
		2	N.F.	0	-	460
		3	I.	2.5	170	-
		4	N.F.	0	-	420
		1	I.E.	-	20	-
		2	N.F.	0	-	385
		3	I.E.	-	20	-
		4	N.F.	0	-	490
	11	1	I.	2	30	-
		2	N.F.	0	-	190
		3	I.	2	30	-
		4	N.F.	0	-	170
		1	I.	2	40	-
		2	N.F.	0	-	180
		3	I.	2	50	-
		4	N.F.	0	-	160
	12	1	I.	1	50	-
		2	N.F.	0	-	210
		3	I.	1	60	-
		4	N.F.	0	-	175
		1	I.E.	-	45	-
		2	N.F.	0	-	185
		3	I.E.	-	55	-
		4	N.F.	0	-	210
		1	I.	2	85	-
		2	N.F.	0	-	255
		3	N.F.	0	-	210
		4	N.F.	0	-	225
	13	1	I.E.	-	30	-
		2	N.F.	0	-	455
		3	I.E.	-	30	-
		4	N.F.	0	-	460
		1	N.F.	0	-	515
		2	I.	3	110	-
		3	N.F.	0	-	570
		4	I.	3	245	-

(1) I.E. = cracks visible on internal face and external face of wall.
I. = crack visible on internal face of wall. N.F. = no visible crack.

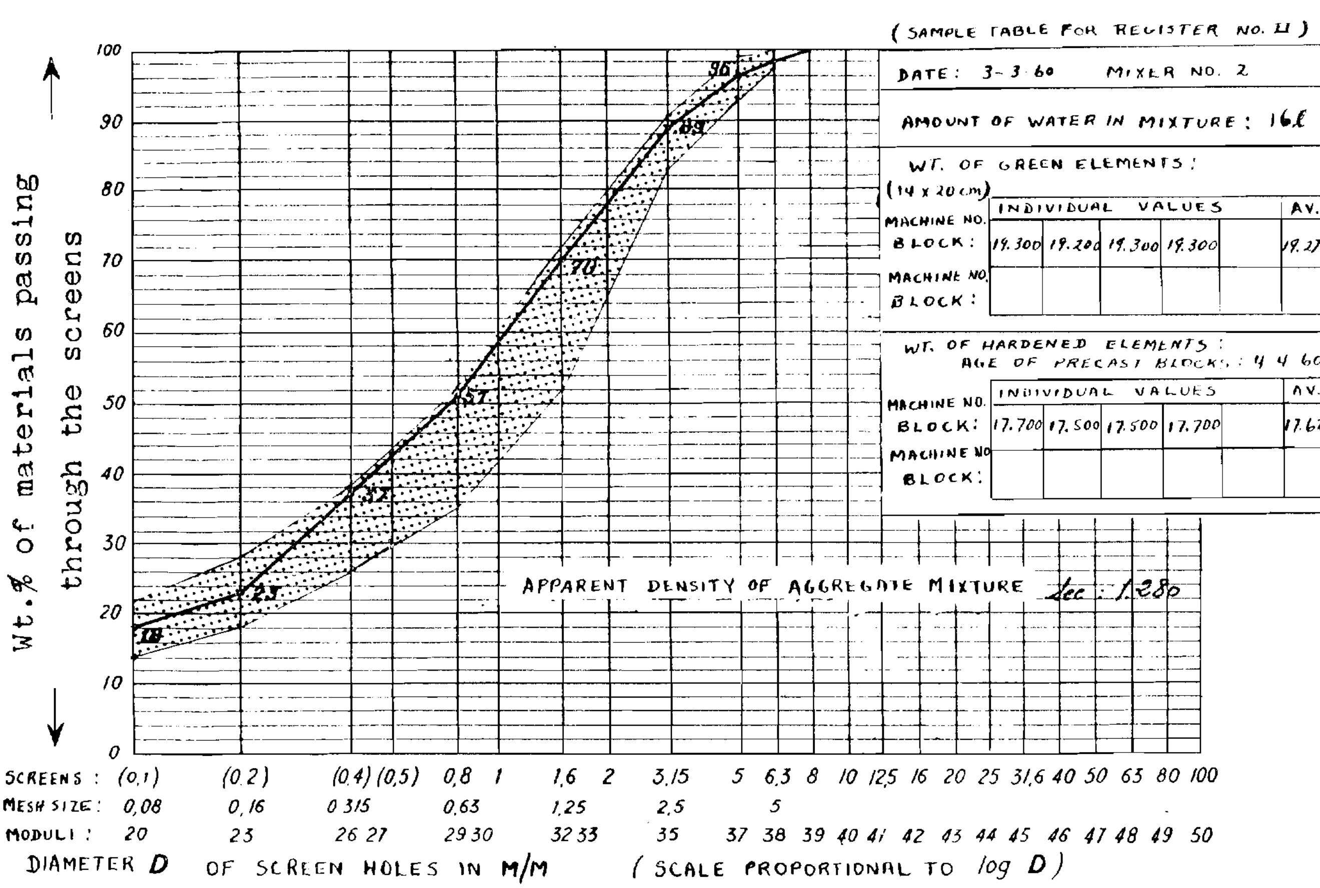


Fig. 1

Model of a manufacturing check chart

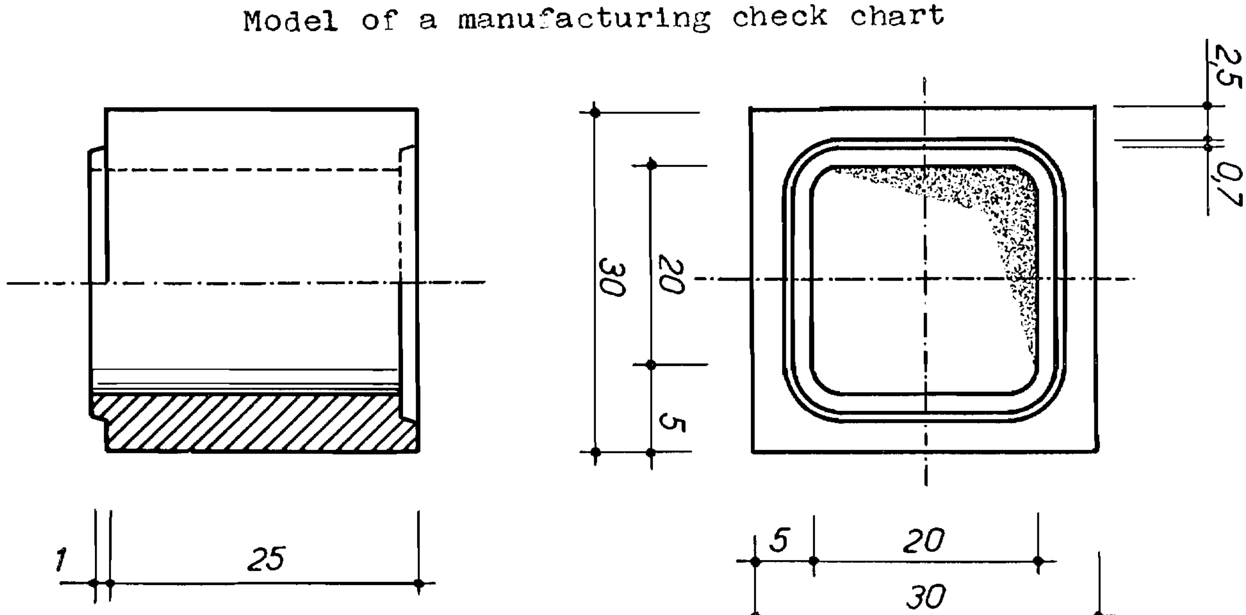


Fig. 2

Shape and dimensions of blocks produced at the Experimental Station

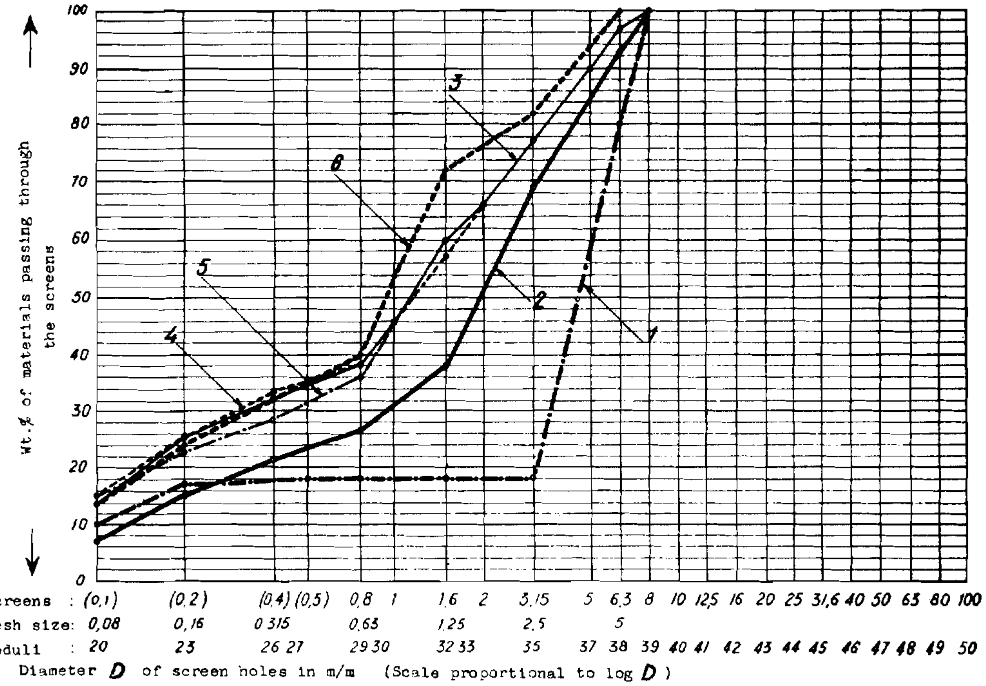


Fig. 3

Sieve analysis of concretes used in producing the precast blocks at the Experimental Station

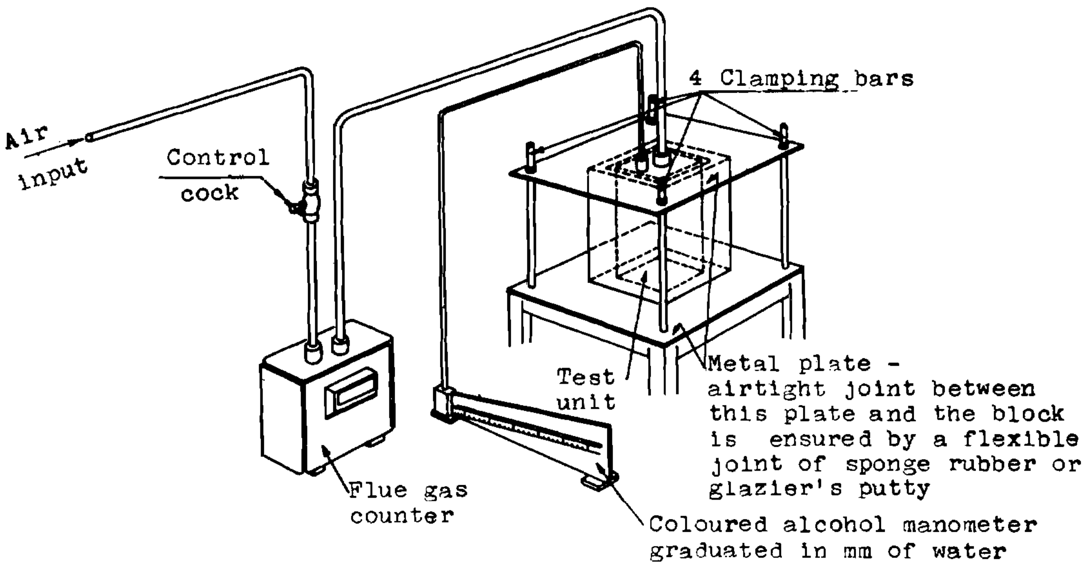


Fig. 4

Diagram of air permeability measuring equipment

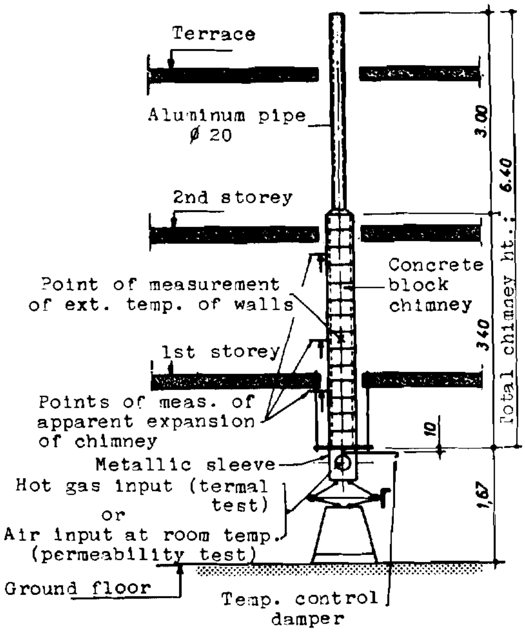


Fig. 5

Diagram of chimney assembly. - Research tests (For approval tests the assembly is the same except that the chimney is built of blocks over its entire height and is coated with plaster)

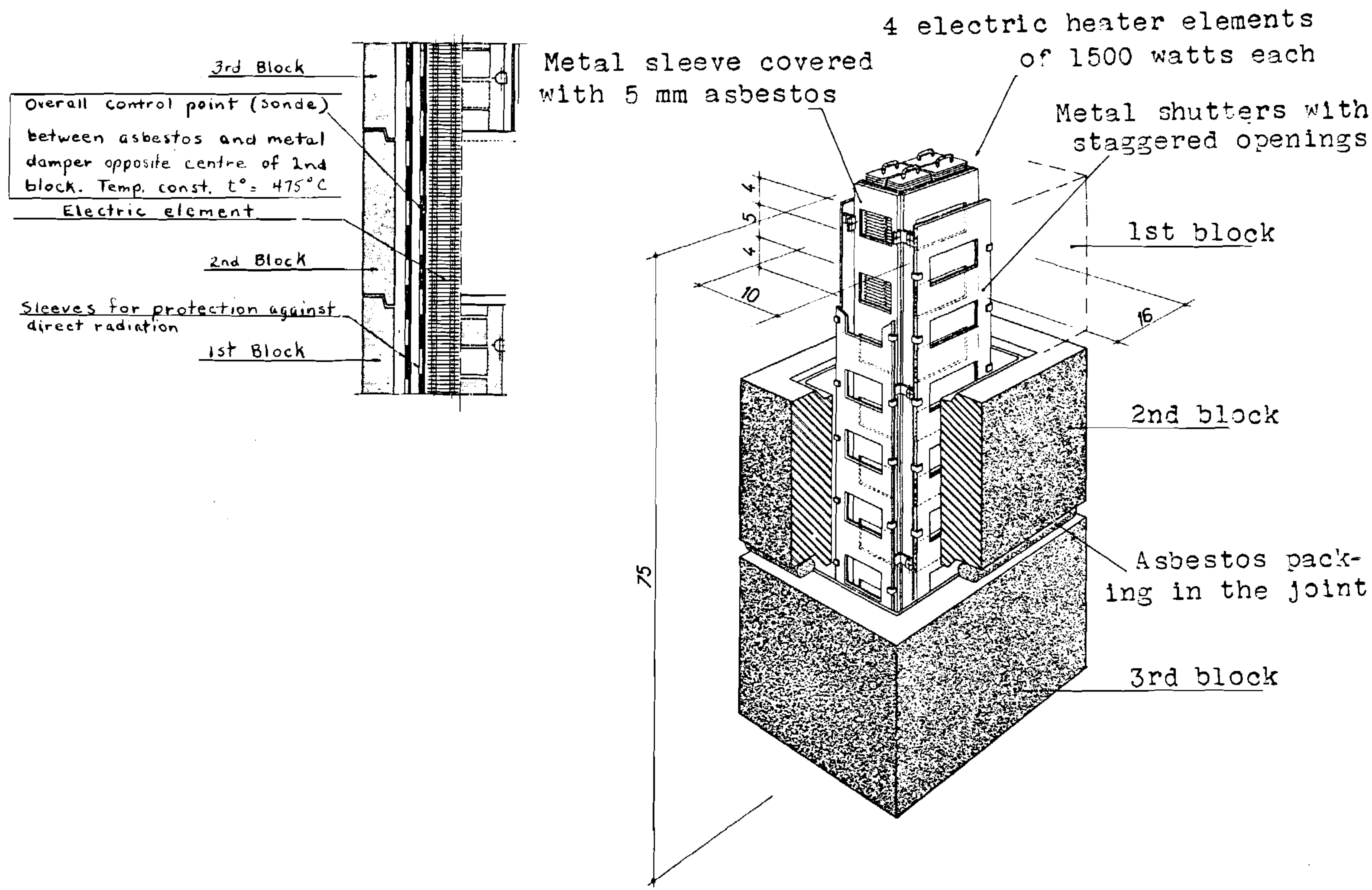


Fig. 6

Design of apparatus for simplified thermal test
(apparatus for 14 • 20 cm blocks).
Position of temperature control point

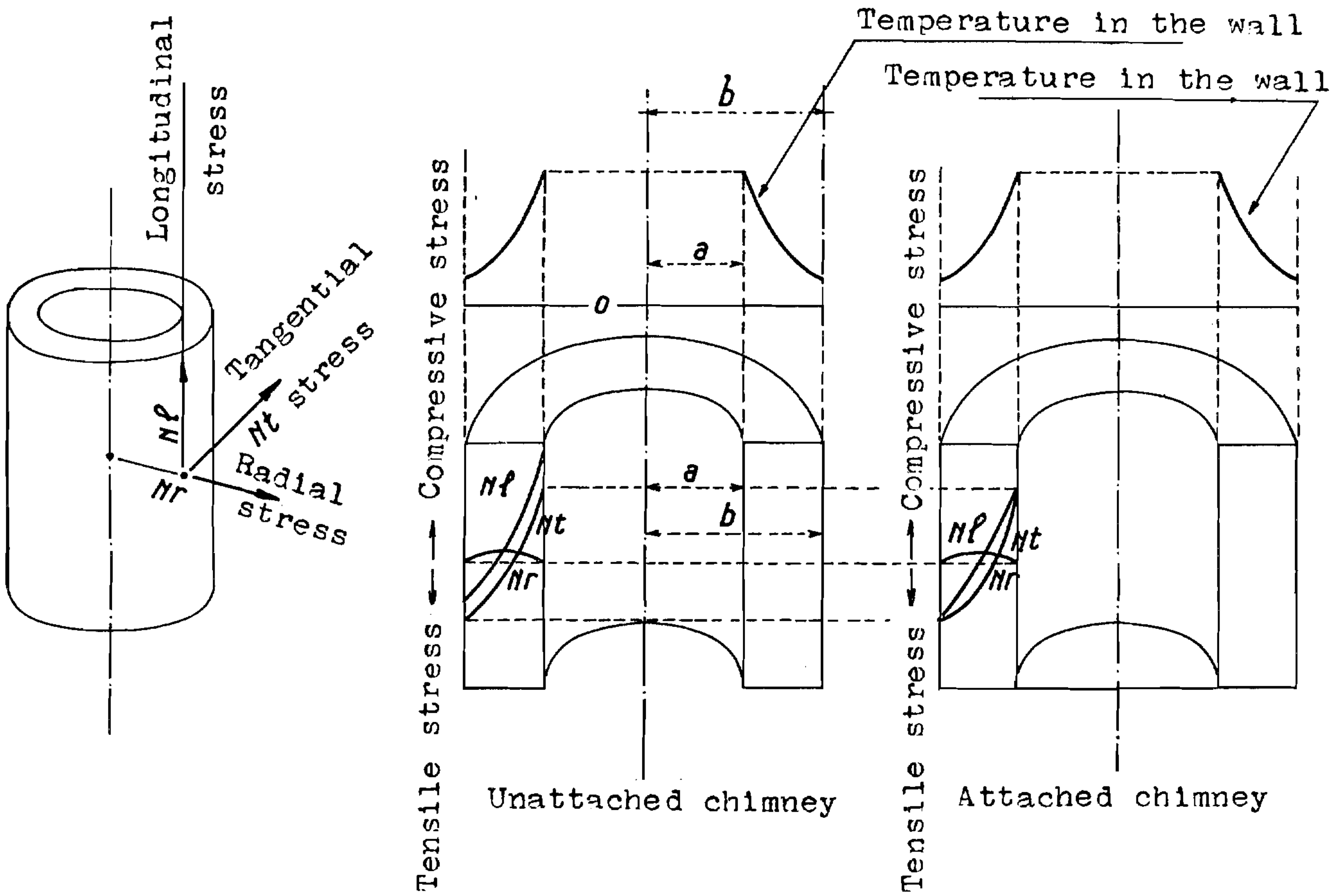


Fig. 7

Theoretical stress distribution in the walls of a cylindrical chimney unit assumed to be made of a homogeneous material which does not shrink and to be at uniform temperature over its entire height, under continuous burning (taken from "Industries Thermiques", June 1957)

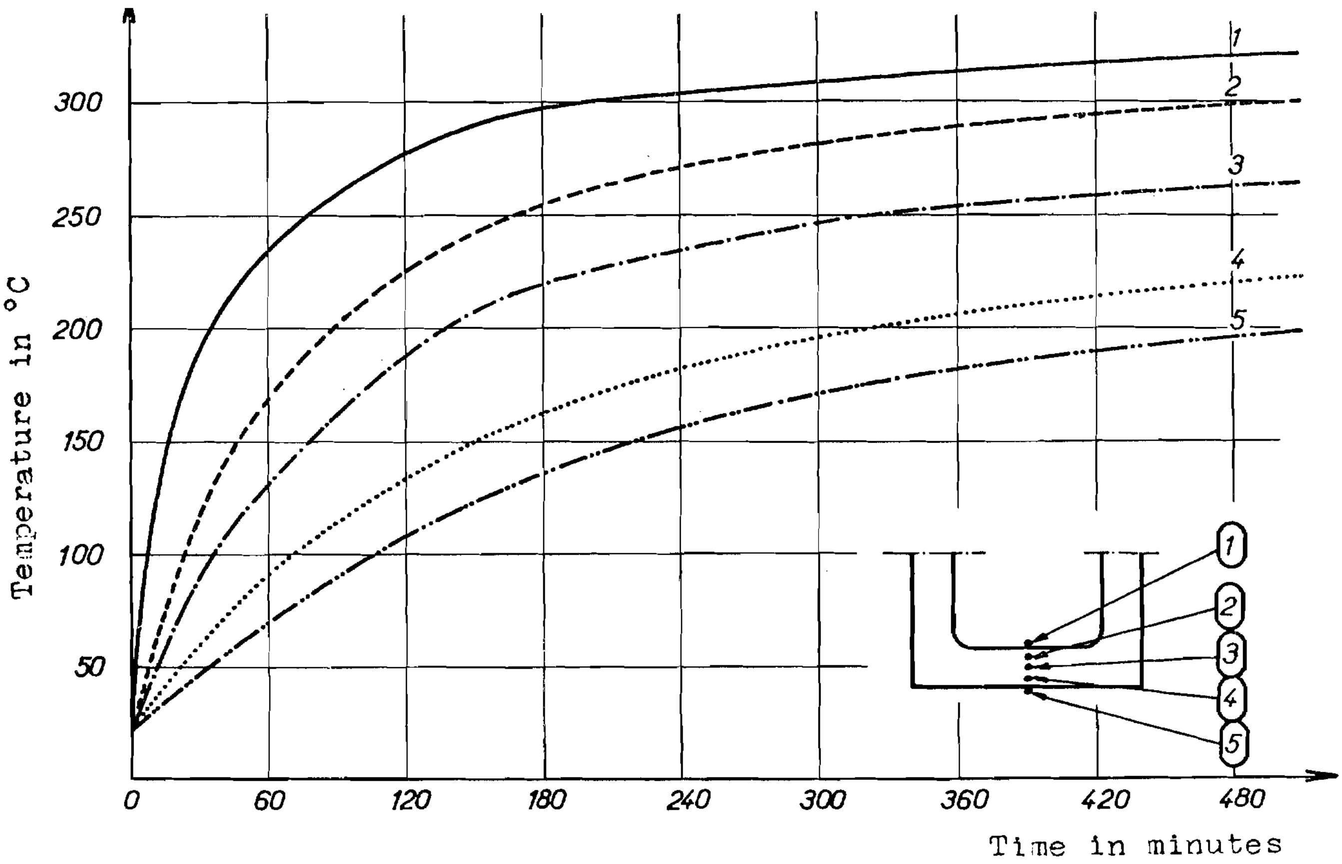


Fig. 8

Distribution of temperatures through the thickness of a wall (pozzolana concrete block with solid 5 cm walls, individual test, control temperature 475°C)

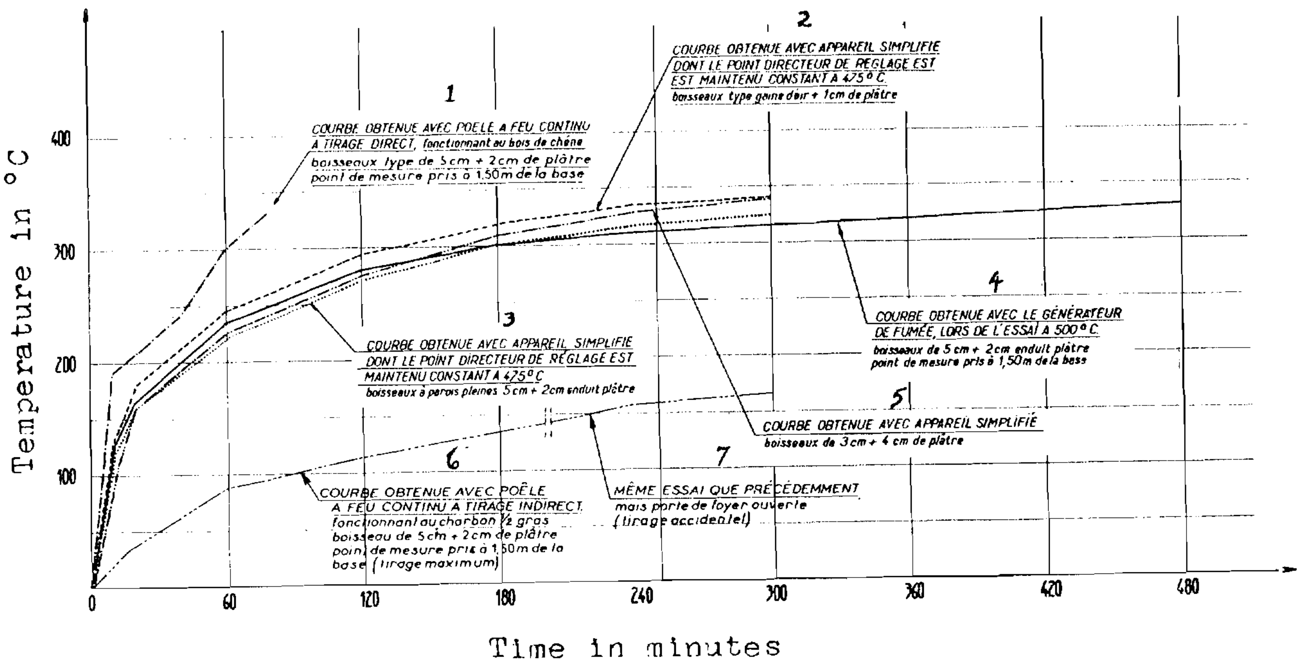


Fig. 9

Internal wall temperature as a function of the type of block and test apparatus

1

Curve obtained with continuous burning, direct draught stove burning oak
Blocks 5 cm + 2 cm plaster
Measured at 1.50 m from base

2

Curve obtained with simplified apparatus, the overall control point being kept constant at 475°C
Block type: air sleeve + 1 cm plaster

3

Curve obtained with simplified apparatus with overall control point kept constant at 475°C
Solid wall blocks 5 cm + 2 cm plaster coat

4

Curve obtained with the smoke generator during the 500°C test
5 cm block + 2 cm plaster coat
Measured at 1.50 m from base

5

Curve obtained with simplified apparatus
3 cm block + 4 cm plaster

6

Curve obtained with continuously burning, indirect draught stove burning semi-bituminous coal
5 cm block + 2 cm plaster
Point of measurement 1.50 m from base (maximum draught)

7

Same test as before but with ash pit door open (accidental draught)

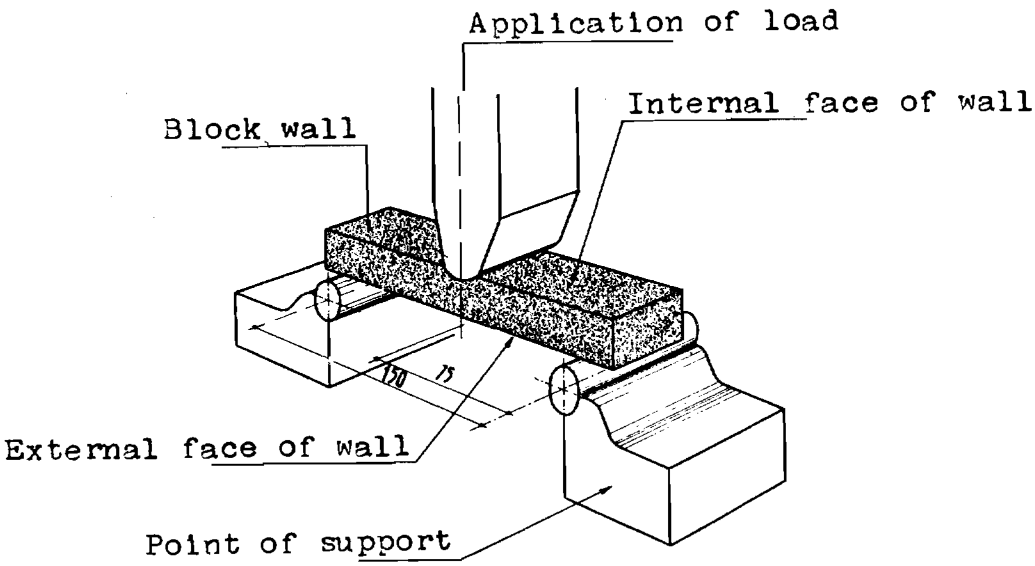


Fig. 10

Diagram of bending test of a block wall