

## Masonry Units Heat-Insulating from No-Fines Lightweight Concrete (Pumice)

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**ABSTRACT:** Owners and building proprietors are demanding high-capacity heat-insulating exterior masonry component, specifically for further energy saving. The thermal conductivity of such materials shall be considerably lower than as specified in DIN 4108-4. The major variables influencing the thermal conductivity of masonry materials are illustrated by taking blocks made from no-fines lightweight concrete as an example, and notes for an optimised product development are also provided. A description is given for procedures to demonstrate the thermal conductivity of the masonry units by performing measurements on the masonry material and the subsequent calculations that have to be made.

### 1 INTRODUCTION

It is necessary to make allowance for the influences from the masonry material, the moisture of the material, the ratio of core holes in the block as well as the recess configuration, in the development of masonry units where the thermal conductivity shall be considerably lower than the values given in DIN 4108-4. A further possibility constitutes such units where the core holes are filled with an insulating material. Legal requirements shall also be observed in the development of these products, and also the thermal conductivity of the units shall be demonstrated by established procedures.

### 2 PROBLEM DEFINITION

In view of today's policy of predatory cutting price, only those can make money who actively take part in the market by offering exceptional products. It is for this reason that high-end masonry units with extremely low values of  $A\# = 0.10 \text{ W/m}^2\text{K}$  for the thermal conductivity are now available in Germany.

According to DIN 4108-4:1991-11, a minimum of  $A\# = 0.14 \text{ W/m}^2\text{K}$  is only possible for masonry walls. The German construction supervisory authorities permit however, alternative, more accurate, evidence whereby the benefit of individual masonry units can be shown to their best advantage in terms of the block material and optimisation of the core-hole configuration. The procedure for demonstrating this by conducting measurements on the masonry materials and the subsequent calculation are

described in this article. Explanatory notes on the rules in the Construction Regulations List A - Appendix 2.7 (Bauregelliste, 1998) is also given. The method is principally equivalent to procedures in future European norms and standards. The major variables influencing the thermal conductivity of the masonry materials as well as notes for an optimized product development process, are given by taking units made from no-fines lightweight concrete as an example for this.

### 3 MASONRY MATERIALS

The starting point for all considerations is the masonry material to be used. The most important influencing variable is the apparent specific gravity of the dry substance here.

This is because the lighter material has the better the heat-insulating characteristics. The apparent specific gravity of the dry material are influenced by the apparent specific gravity of the aggregate and the percentile porosity attributable to the no-fines proportion (particle size distribution). The bulk density of the chosen aggregate mixture describes both influencing variables by a single parameter. The quantity of cementing material also has an influence on the apparent specific gravity of the dry material. The more cement that is used, the higher is the weight and hence the higher the thermal conductivity is.

The apparent specific gravity of dry material is the major, though not the only, influencing variable for describing the thermal conductivity. The differences between the various types of aggregates are minor.

though these are often crucial in determining the product's competitiveness. Thus natural pumice has a lower thermal conductivity than expanded concrete. The differences in the thermal conductivity of cementing materials may not be overlooked here. Cement is not an ideal material from the thermal conductivity point of view, and the thermal conductivity of anhydrous lime is lower. (KS-Yali), Calimax block (Calimax-Warmedimmstein) and aerated-concrete units utilize this favourable property of using anhydrous lime as the cementing material.

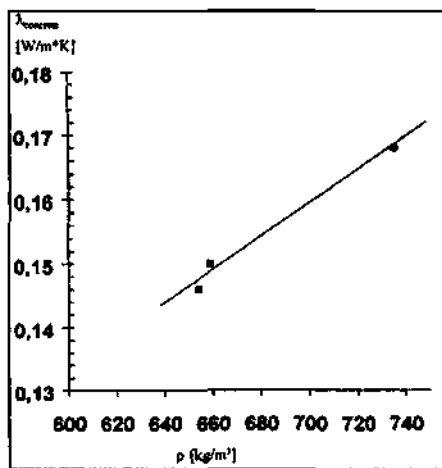


Figure 1. Example of a regression between material density and measured test values of thermal conductivity

The thermal conductivity of the masonry material has to be measured in the two-plate equipment in accordance with DIN 52612-1:1979-09 in order to determine all these characteristics. Three measurements per class of apparent specific gravity make it possible to establish a relationship between the apparent specific gravity of the dry material and the thermal conductivity of a particular masonry material. Then the apparent specific gravity of dry material is determined with a sufficient margin of safety at the upper limit of the apparent specific gravity of the material to be used for the unit, and the initial value for the thermal conductivity can then be read off at this point for calculating the class for the apparent specific gravity (Fig. 1). The Construction Regulations List (Bauregelliste, 1998) requires classification by means of a table for the value that is determined. ISO 10456:1997(E) uses a statistical evaluation technique for the data in order to compensate for scatter by the values that are measured.

Measurements are not necessary in every case. It is also possible in accordance with the Construction Regulations List to use the values given in DIN 4108-4:1991-11, whereby a moisture factor, as de-

scribed in the following section, is already included. Should the recipe, and hence the masonry material, not have undergone any change, then values from W-approvals given earlier can be taken for further use. Additional tables of thermal conductivity values for lightweight concrete made with no-fines of internal porosity are given in prEN 1745:1994, prEN 1520:1997 and prEN 12524:1996.

#### 4 MOISTURE FACTOR

The material in the construction is not as favourable as in the case of the oven-dried samples used for measurements. The moisture that is naturally present in the substance lowers the heat-insulation properties. The influence of this on the thermal conductivity is taken into account by a moisture factor  $Z$ . Higher values of the between 20% and 25% are given for a flat-rate increase in the DIN 52612-2:1984-06.

This includes a certain margin of safety as in all norms. More accurate evidence is therefore allowed by the Construction Regulations List. Thermal conductivity measurements are performed to this end on moist samples and a relationship there by established between the moisture content and the thermal conductivity of a particular masonry material. Yet which moisture content in the subsequent construction will then set in Investigations (Schule, 1999) carried out on constructions to this end have shown that the reference moisture content according to DIN 52620:1991-04 corresponds to this value. The sorption moisture is measured and the value for the moisture factor  $Z$  is determined in this way for the masonry material in question (Fig. 2).

Characteristic values for the moisture content are also found in prEN 1745:1994, prEN 1520:1997, prEN 12524:1996, ISO 10456:1997(E) as well as in the draft for DIN V 4108-4:1998-10. In addition to this, some of the norms include factors for converting the thermal conductivity for the various moisture content (by mass and by volume) and for the average temperatures of the materials.

#### 5 CORE-HOLE RATIO

The next step is to define the core-hole ratio for the block. The manufacturer wishes this of course to be as high as possible. Selling voids are always the best method to earn money. The thermal conductivity of the block is furthermore lowered by a favorable arrangement for the holes in the core.

Table 1. Thermal conductivity values of recesses for air pockets, according to DIN EN ISO 6946-1

Thickness, d [mm]	Thermal Conductivity, $\lambda$ [W/(m*K)]	Thermal Resistance, R [(m <sup>2</sup> *K/W)]
5	0.046	0.11
7	0.054	0.13
10	0.067	0.15
15	0.088	0.17
20	0.111	0.18
25	0.139	0.18

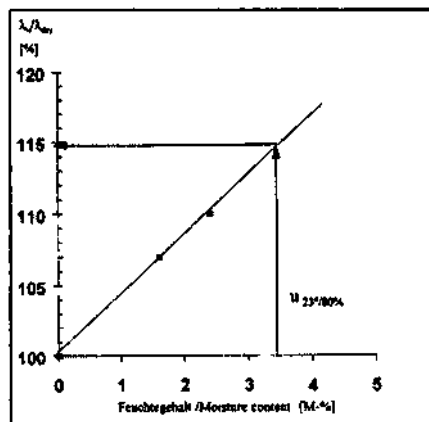


Figure 2. Example of moisture content vs thermal conductivity

A higher core-hole ratio also means a higher apparent specific gravity of the masonry unit for the same apparent specific gravity of the material used. Savings in the expensive lightweight aggregate materials can thus be made in this way. Increasing the apparent specific gravity does however also lead to an increase in the thermal conductivity of the masonry material (Fig. 1) and hence that of the whole unit as well. The strength of the high-capacity heating-insulating masonry materials is only low, a high core-hole ratio reduces the load-bearing cross-section, and hence the mechanical strength is lower as well.

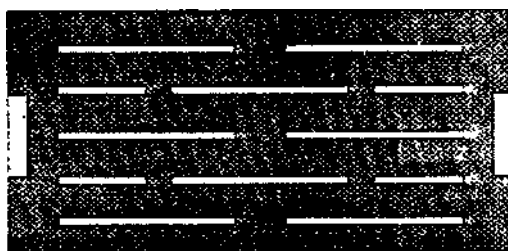


Figure 3. Unfavorable slit design

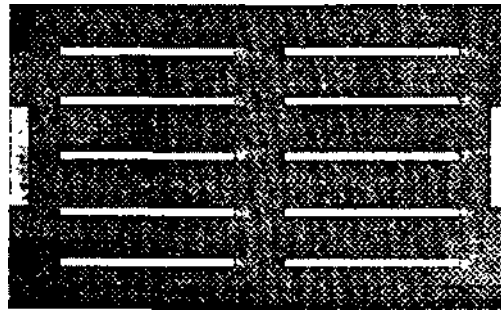


Figure 4. Favorable design with small slits

Also to be observed here is a limitation of the core-hole ratio in the various specifications for masonry materials (Sariisik, 2001).

Figure 5. Favorable design with regular slits

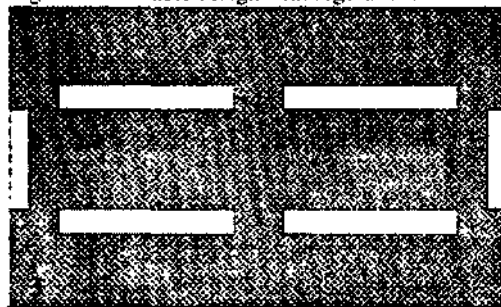


Table 2. Results of three-dimensional calculations with mortar LM 21

Block Configuration as in	Thermal Cond., X R ST of the masonry material (W/m*K)	Thermal Cond., X ,nv of the cavities [W/(m*K)]	Calculated X [W/(m*K)]	U-value include plaster on both sides [W/(m <sup>2</sup> *K)]
Figure 3	LAC 0.14	air 0.139	0.145	0.44
Figure 4	LAC 0.14	air 0.067	0.132	0.40
Figure 5	LAC 0.14	air 0.067	0.131	0.40
Figure 4	concrete 2.10	polystyrene 0.04	0.821	1.72
Figure 5	concrete 2.10	polystyrene 0.04	0.759	1.63

## 6 RECESS SHAPES

The thermal conductivity of a recess in a masonry block depends on the width of the recess. Table 1 illustrates the relationship in that this can be calculated using the equations given in DIN EN ISO 6946:1996-11 as a function of the geometry. The following conclusions can be drawn from the table:

- The more narrow the recesses are, the lower is the thermal conductivity.
- The insulation by 4 recesses each of 5 mm in width is better by a factor of 2.4 than one recess 20 mm in width.
- The insulation by recesses of a width less than 4 mm is even better than using commercial available insulating materials.

The objective in designing block must therefore be an arrangement for as many narrow recesses as possible. The only limitation to this goal is by the rib structure between the recesses. The minimum width for these ribs are given by the engineering in production of charging the mold with appropriate material, and this depends both on the largest-grain size as well as on the plasticity of the mix. (Liapor Super K.) has 10 recesses for a unit width of 30 cm and a rib thickness of 19 mm. This is only possible for technical reasons in manufacturing by using a small largest-grain size and a spherical shape for the aggregate admixed with the expanded concrete. Figure 3 and 4 show the clearly apparent influence of the recess geometry. Both blocks have the same core-hole ratio of 12% here. The results of a three-dimensional heat-flow calculation are shown in Table 2. The thermal conductivity is 9% lower in the case of the more favourable core-hole arrangement of narrow recesses (Sariisik, 2001).

## 7 ARRANGEMENT OF RECESSES

Figure 5 shows a block having exactly the same core-hole ratio and made of the same masonry material as in Fig. 4. The only difference is that the arrangement of recesses over the cross-section is more

regular. The calculations give a reduction in of less than 1%. Such an optimisation thus only realises slight advantages in blocks made of highly heat-insulating masonry materials. The key to the design of the masonry unit is the number and fineness of the recesses.

## 8 FILLING WITH INSULATING MATERIAL

A different situation is given where the cavities are filled with insulating material. This is because there is difference in thermal conductivity between the masonry material and the insulating material used. The difference is very high here and the influence from a consequential arrangement of the recesses in order to avoid thermal bridges is very significant. Figure 4 and 5 were re-calculated in the same way as before yet the thermal conductivity of polystyrene was taken for the cavities and concrete was used as the masonry material. The results are shown in Table 2. In this case, the thermal conductivity is lowered by some 8% by the more favorable core-hole configuration with a regular arrangement of between recesses and ribs.

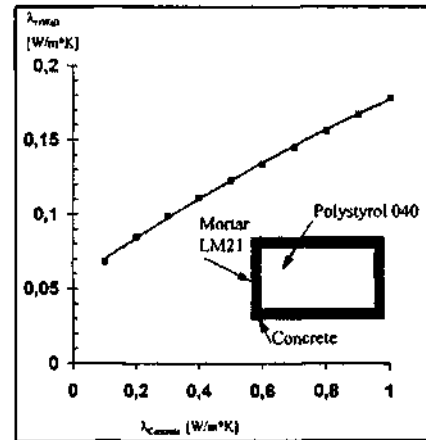


Figure 6. Thermal conductivity of a given block with variation of the material

The proportion of insulating material should be chosen to be as large as possible in order to achieve a low thermal conductivity for the whole masonry unit. Thermal bridges are to be avoided and a low thermal conductivity for the masonry material is to be aimed for. Figure 6 shows the values for the thermal conductivity that can be attained using different combinations of materials for a given block configuration (Sariisik, 2001).

## 9 CALCULATIONS

The thermal conductivity of the masonry unit can be determined once the characteristic of the materials to be used have been established and the configuration for the block has been defined. The influence of the core-hole configuration, the type of mortar used, whether filled or empty mortar pockets, etc., is taken into account in the calculations for the three-dimensional heat flow. The result from the calculations are the thermal conductivity  $X$ , for the masonry structure.

A list of possible computing programs for this is included in (Christoph, Z., Thomas F., 1998). The DIN EN ISO 10211-1:1995-11 also provides notes on the accuracy requirements for the programs and the calculations. Examples of calculations are given in prEN 1745:1994 for reference. These examples cannot be verified because no dimensions for the geometry's are given here.

## 10 REGULATIONS FROM THE CONSTRUCTION SUPERVISORY AUTHORITIES

The values calculated for A#, the thermal conductivity of the masonry construction, are given with an accuracy to the second decimal place. A classification table based on the principles of statistical techniques is given to this end in the Construction Regulations List, Appendix 2.7. This classification table is the source of much joy or disappointment depending on whether the target value is just reached or slightly exceeded. However it does give greater transparency in the market and enables a clearer differentiation between individual products.

In view of today's policy of predatory cutting price, only those can make money who actively take part in the market by offering exceptional products.

Formal rules have to be observed in order that the values determined by a demonstration of the thermal protection may be used. On the one hand, the values can be listed in a certificate of approval from the German Institute for Construction Engineering (DIBt). For masonry units meeting the particular requirements of each norm, more favourable values can be determined in comparison to the DIN 4108-4 in the calculations for masonry constructions made using walling components as a function of the type of mortar within the scope of the harmonisation procedures given in Appendix 2.7 of the Construction Regulations List A Part I (Bauregelliste, 1998) from the surveillance offices and established by the certifying authorities. It can then be attested in the certificate of compliance that the manufacturer can present in combination with the symbol of compliance (Ü symbol) as a major selling point (Lühr, 1999). At the present time, the established value that has been calculated to published in the Federal Gazette.

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