THE DEVELOPMENT OF NEW BUILDING MATERIALS IN GERMANY FROM 1919 ONWARDS AND THEIR STANDARDIZATION USING THE EXAMPLE OF HOLLOW AND PERFORATED CLAY BRICKS

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hollow clay bricks, perforated clay bricks, thermal conductivity, standards, patents, National Technical Approvals

Abstract

The aim of saving heat, and hence energy, is demonstrated by the development of hollow and perforated clay bricks. A study of this subject reveals that the developments following the First and Second World Wars were fundamentally different. Various hollow bricks were developed from 1919 onwards, which were first patented and then approved for use in construction works. The multiplicity of types was then curbed by the introduction of DIN 4151 (perforated bricks for loadbearing masonry).

There was no similar development after the Second World War; standard clay bricks were used without exception. Not until the oil crisis of 1973 did we see an upsurge in development similar to that after 1919. However, the developments concentrated on existing technical improvements to lower the thermal conductivity; up to five possible features were varied. Further analysis shows the relationship between the development booms to reduce the thermal conductivity of hollow/perforated clay bricks and the political measures in the form of legislation covering thermal insulation and energy conservation.

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1919–1945: DIVERSE DEVELOPMENTS UP TO 1941 AND STANDARDIZATION

In the years following the First World War, the fuel shortages, caused by the reparation payments of the victorious Western powers, unleashed a torrent of innovation activity in the brickmaking industry. The developers focused on hollow clay bricks – and bricks with reduced porosity – in particular, and the aims of research and development were as follows:

- to reduce the consumption of clay,
- to reduce the cost of fuel by reducing mass and layer thicknesses,
- to reduce the cost of transport, and
- to reduce the cost of heating buildings by lowering the thermal conductivity.

Twelve hollow clay bricks were patented between 1919 and 1945.[2] The R&D work carried out in the brickworks mainly concerned technical implementation issues; both the preparation of the clay and establishing a straightforward production sequence presented problems.[3] Many different bricks were developed during this phase. Five types of 29 different hollow and perforated clay bricks in various formats were mentioned in *Tonindustriekalender 1932*.[4]

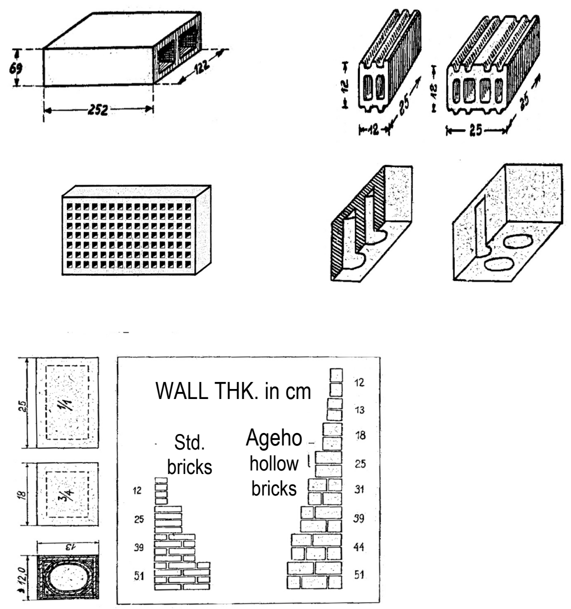

Figure 1: Five different types of hollow/perforated clay brick

2 Own research in the archives of the German Patent Office, Berlin; nine hollow/perforated bricks were patented up to 1919.

3 TIZ 1919, No. 32, p. 228; TIZ 1920, No. 3, p. 3f.; TIZ 1922, No. 17, p. 1; TIZ 1926, No. 71, p. 1259f.; TIZ 1929, No. 52, p. 927f.; TIZ 1929, p. 1617f.; TIZ 1930, No. 10, p. 162f.; TIZ 1931, No. 66, p. 947f.

4 *Tonindustriekalender 1932*, pp. 8–39. The following typologies were distinguished: open on two sides (through-hole brick), multi-hole brick (horizontally perforated brick), hollow brick closed on five sides, cellular brick (i.e. closed on all sides), perforated/hollow brick (horizontally perforated). Further overviews of bricks from this period can be found in: Siedler 1932, pp. 108, 275ff.; Siedler 1934, p. 82ff.; Kuchler 1933; Hofherr 1933.

In 1937 the first standardization efforts concerning hollow clay bricks resulted in the following:

- The height of the brick must be a multiple of the height of a standard brick.[5]
- Definitions of the geometry of the voids and the webs.

A National Technical Approval regulated building with these bricks, and covered the whole of the German state from 8 November 1937.[6] Most approvals were withdrawn per decree in 1941 and only certain perforated clay bricks were included in the new DIN 4151 (perforated clay bricks for loadbearing masonry).[7]

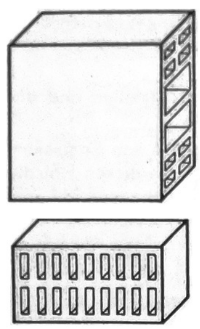

Figure 2: Perforated clay brick for loadbearing masonry according to DIN 4151

Thermal conductivity was first investigated scientifically in the mid-1930s. Joseph Sebastian Cammerer (1892–1983) in particular contributed much to this field and was quoted in subsequent publications on this subject right up until the 1960s. Pre-war documents were already specifying λ values of 0.3–0.5 kcal/mh°C (≈ 0.35–0.58 W/mK) for clay masonry.[8]
This was even taken into account in DIN 4110 (approval of new forms of construction) when it appeared in 1937. Maximum k values (corresponding to today's U values) were specified which, allowing for wall thicknesses, corresponded to Cammerer's λ values of 1936.

1945–1967: INNOVATION STOPPED BY STANDARDS?

A procedure was sought for making standards obligatory in the building industry.[9] Enforcement took place by anchoring the standards in three areas:

- Standards as standardized codes of practice (*Einheitlich Technische Baubestimmungen*, ETB)
- Standards as mandatory standards in construction
- Standards as the basis for the German Construction Contract Procedures (*Vergabe- und Vertragsordnung für Bauleistungen*, VOB)[10]

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5 ZdB, 30 Jun 1938, p. 825, in: Berlitz 1940, p. 33.
6 Berlitz 1940, p. 1.
7 Prussian Finance Ministry decree, 7 Mar 1941. See also *Reichsarbeitsblatt*, pt. I, No. 5, 1941.
8 TIZ 1936 No. 10, p. 128; Cammerer 1936, p. 31; TIZ 1936, No. 24, p. 306; TIZ 1936, No. 10, p. 128; TIZ 1942, No. 2/4, p. 25.
9 Frommhold 1957, p. 29.
10 A tabular overview of the respective type of validity can be found in Braun, Gerhard: *Baunormung, Bauforschung. Neue Erkenntnisse der Bautechnik; Beiträge namhafter Fachleute zu neuen Erkenntnissen auf d. Gesamtgebiet des Bauwesens*, Berlin. This series appeared annually from 1962 to 1971.

Standards as standardized codes of practice (ETBs)

At the level of the German federal states, standards were anchored in the federal state building regulations in the form of standardized codes of practice (*Einheitlich Technische Baubestimmungen*, ETB). They had been introduced in the same way as early as 1932, albeit throughout the whole German state at that time.[11] These ETB standards were DIN standards drawn up in collaboration with the ETB Committee, which recommended to the federal state building authorities which standards should be included in the federal state building regulations.[12]

However, the ETB Committee also played an active role in standardization. For the committee had also "set itself the task of creating a comprehensive set of standards for building physics issues as well such that the building regulations could be enacted as a framework specification with objectives but without including technical details", and ensuring that "codes of practice should be enough to concretize the general requirements of the building regulations".[13] Both DIN 105 (clay masonry units) and DIN 4108 (thermal insulation and energy economy in buildings) were ETBs.[14]

Standards as mandatory standards in construction

Hellmich was still refusing to give standards a legislative character as late as 1941.[15] After the war, however, it was seen as necessary to attach a more binding character to standards because "only the general use of standards in design and construction can create the conditions for rationalising the design and construction of structures, which is the aim of standardization, and contribute to the aim of reducing the cost of construction".[16] This fact seemed to be inescapable, especially for the housing so desperately needed after the war. The aim of Germany's 1st Housebuilding Act (*1. Wohnungsbaugesetz*), passed in 1950, was to promote housebuilding by

- using public funding (cl. 3, 13–22),
- setting up guarantees (cl. 5),
- exploiting tax concessions (cl. 7–11),
- making available land for building (cl. 12), and
- relaxing controls in the housing market (cl. 22–27).[17]

The aim was to lower the cost of building.[18] And that also included DIN 105.[19] According to the building regulations,[20] DIN 4108 initially "only" applied to housebuilding as an ETB

11 Frommhold 1957, pp. 10, 27.
12 According to Frommhold, the Committee's instructions were mostly followed, see Frommhold 1957, p. 27f. References to the possibility of deviating from the codes of practice, specified in the 1960 Model Building Code (*Musterbauordnung*, MBO) when another solution satisfies the general requirements of para. 1 to the same extent, were limited in federal state building regulations: Baden-Württemberg, Bavaria and Berlin referred "in particular" to the ETBs; North Rhine-Westphalia and Schleswig-Holstein referred in a neutral way to the ETBs; Rhineland Palatinate specified the ETBs as those that are "also" valid as acknowledged construction regulations. See Haase 1968, p. 17ff.
13 Bub 1978, p. 99.
14 See Braun 1966, pp. 83, 103.
15 Hellmich 1941, p. 3.
16 Frommhold 1957, p. 29.
17 *1. Wohnungsbaugesetz*, 24 Apr 1950.
18 *1. Wohnungsbaugesetz*, 24 Apr 1950, cl. 6, para.1.

according to the building regulations. It was not until 1955 that it became a mandatory standard for housing.[21]

Standards as the basis for the German Construction Contract Procedures (VOB)

After legislation dealing with the award of contracts throughout the German state was rejected by the Reichstag in March 1921,[22] a voluntary committee was set up to create uniform guidelines for awarding contracts for the provision of products and services on national and federal state levels. Although the initiative came from state government, the basis was a voluntary activity, similar to the DIN committees, in which representatives from various bodies gathered on a voluntary basis.

Legislation for the award of contracts for building products and services was introduced in 1926.[23] This was the result of the cooperation of representatives from the federal state governments, German cities and towns, German industry, German architectural and engineering bodies, etc. The general provisions dealing with contractual conditions and awarding contracts were published as standard sheets.

Innovation stopped by the dominance of standards in construction

It could be assumed that the introduction of a standard would also present the best technical values. However, when DIN 4108 (thermal insulation and energy economy in buildings) was introduced in 1952, the lowest λ value for clay bricks was taken to be 0.45 kcal/mh°C (≈ 0.52 W/mK), even though clay bricks with much better insulating values had been specified almost 20 years previously. Fig. 3 shows the thermal conductivity requirements. It can be seen that, over the period considered, it was not necessary to reduce the thermal conductivity of clay bricks on the basis of DIN 4108 requirements regarding the thermal transmittance values for walls. Indeed, in 1952 the U value requirements in DIN 4108 corresponded to the material parameters for clay bricks dating from 1936.[24]

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19 Frommhold 1957, p. 29.

20 For example, listed as an ETB for Berlin in Braun 1962, p. 103.

21 Schornstein 1955, p. 77.

22 Preface to *Verdingungsordnung für Bauleistungen*, Berlin 1926, p. 1; *Reichstagsprotokolle* 1921, minutes of 79th session, 9 Mar 1921, retrieved from http://www.reichstagsprotokolle.de/Blatt2_w1_bsb00000032_0000132.html.

23 Preface to *Verdingungsordnung für Bauleistungen*, Berlin 1926, p. 2.

24 Own calculations using the values published by Cammerer in 1936 (Cammerer 1936, Fig. 18, p. 31). The best tabular value for clay bricks (λ = 0.4 kcal/mhºC) was used to calculate the U value (converted to SI units with a factor of 1.163). Taking $U = \lambda/d$ results in a value of 1.27 W/m^{2}K for a 36.5 cm thick wall and hence a value lower than that called for in the DIN standard. Depending on the thermal insulation zone, the DIN values range from 1.53 to 2.22 W/m^{2}K. DIN 4108:1960 also specifies 0.4 kcal/mhºC (= 0.465 W/mK) as the best thermal conductivity for perforated clay bricks.

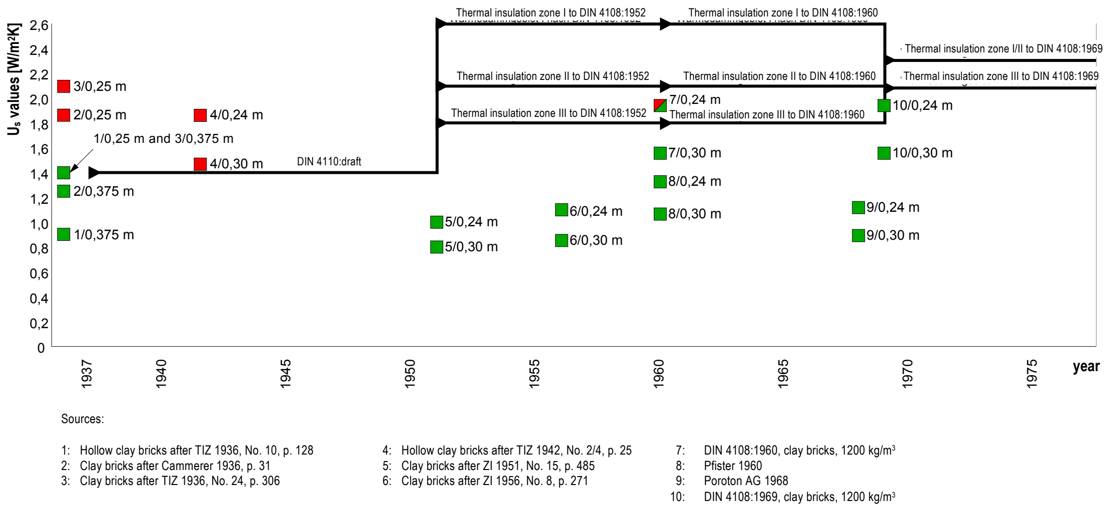

Figure 3: Comparison of requirements in standards regarding thermal transmittance and the thermal transmittance values of clay bricks for given wall thicknesses, determined according to $U \approx \lambda/d$ and plotted against time

1969–1999: TECHNICAL PROGRESS IN THE PATENTS SYSTEM

Three events served to signal a turnaround in research into clay brick products and the way clay brick products were developed and placed on the market:

- 1968: Founding of the *Deutsches Institut für Bautechnik* (DIBt, German Institute of building technology) and the central approval of new building materials associated with that
- 1968: Start of production of Poroton bricks
- 1969: Revision of DIN 105, which permitted the production of clay bricks with fine pores

Innovation due to the requirements of thermal insulation legislation

Between 1955 and 1968 there was just one single patent application in the field of clay bricks:[25] the "Poroton" patent of Sven Fernhof from Sweden for loadbearing perforated clay bricks with fine pores and hence an insulating effect. These bricks became technically possible in Germany in 1968. Limits to heat losses through external walls had been specified in Sweden as long ago as the 1940s. This led to the first research in this field, one outcome of which was the invention of aerated concrete.[26] Therefore, creating fine pores in clay bricks for external loadbearing walls was a logical conclusion and led to the aforementioned clay brick patent, which had been originally applied for in Sweden in 1958.[27]

25 Own research in the archives of the German Patent Office, Berlin, and downloading the files from the portal: https://depatisnet.dpma.de.

26 Information supplied by the Association of Swedish Architects, *Sveriges Arkitekter*, 13 Jan 2014.

27 A reference to the application in Sweden on 15 Mar 1958 is apparent from the US patent; see US patent No. 2.996.389, 15 Aug 1961. The fine pores in Poroton bricks are formed with tiny polystyrene beads, which

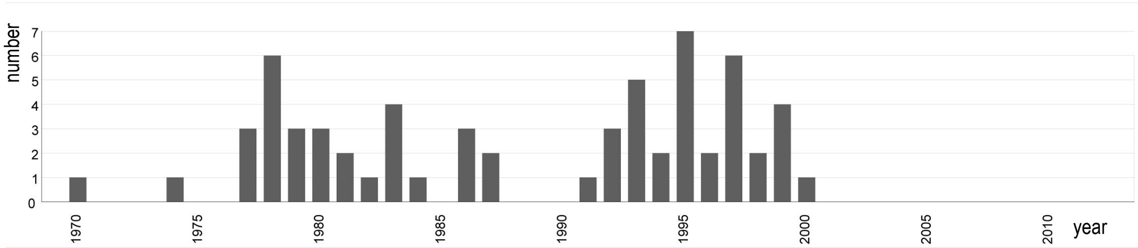

Figure 4: Number of patents, patent applications and utility models over the years 1969–2013

The quantitative evaluation of the patent applications, patents granted and utility models reveals that over the first years of the period considered, 1969–1999, there were only a few isolated patent applications. However, the oil crisis of 1973 triggered a change similar to the years of fuel shortages after the First World War. The 1st Thermal Insulation Act (*1. Wärmeschutzverordnung*, WschVO) of 1977 was enacted as a consequence of energy conservation legislation and saw the Federal Republic of Germany create its first comprehensive set of rules for the thermal insulation of buildings valid for all new construction works.

Only after this act came into force in 1977 do we see a significant increase in the number of patent applications, patents granted and utility models. There is a total of 83 patent applications, patents granted and utility models for the entire period 1969–1999, of which 64 (≙ 77 %) are concerned with reducing the thermal conductivity. Thermal transmittance values of 0.77–1.4 W/m^{2}K were now required for the external walls depending on the ratio between a building's surface area and its volume.[28] On the other hand, there were the values of 1.79–2.58 W/m^{2}K (depending on the thermal insulation zone, I–III) given previously in DIN 4108, which was therefore no longer the relevant standard for specifying thermal conductivity for thermal insulation reasons. Instead, those values only applied to building physics issues, e.g. moisture control.

Patents as information media

For a qualitative assessment, patents and patent applications were studied once again. Evaluating the years 1969–1999 reveals five features for optimizing the thermal performance of clay bricks:

- Offset voids and the web geometry within the brick
- Perpends in the form of tongue and groove systems without mortar[29]
- Parallel bed joints with thin-bed mortar (gauged brickwork)
- Creation of fine pores in the clay
- Large block formats[30]

disintegrate during the firing process leaving behind air-filled voids. These voids do not reduce the load-carrying capacity of the bricks and so a high proportion of polystyrene can be added without affecting the strength of the brick.

28 *1. Wärmeschutzverordnung*, annex 1.

29 A precursor was the mortar pocket, a widening within the perpend. Only this is filled with mortar, the contact faces of the perpend either side abutting each other directly.

30 The aim of large-format clay blocks is the one-brick-thick wall, which can be constructed more rationally and has a lower thermal transmittance because there is no internal joint.

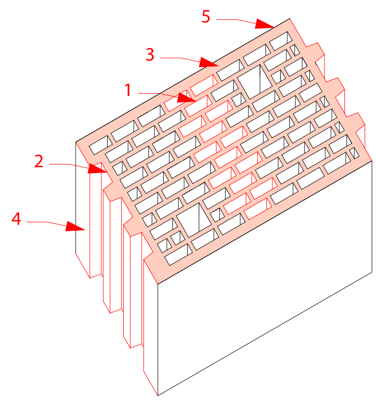

Figure 5: Five features of clay bricks: 1) offset webs and voids, 2) tongue and groove perpends, 3) fine pores, 4) parallel bed joints, 5) large block format

Patents system representing the state of research and technology

Patent EP 584455 dating from 1994 initiated the third phase, starting in 1999. Owing to the very dense honeycomb-type structure of this brick,[31] internal web widths of 1.5–4 mm are regarded as structurally possible, whereas clay bricks previously had web widths of at least 8 mm. A proportion of voids > 50 % plus fine pores led to a theoretical λ value of 0.12 W/mK.[32] This clay brick was the result of a research project by the *Deutsche Bundesstiftung Umwelt* (DBU, German Federal Environmental Foundation) and brick manufacturer Rimmele. The modern honeycomb clay brick appeared on the market as an approved product in 1997.[33] And that started the era of the clay brick with good thermal insulation properties.

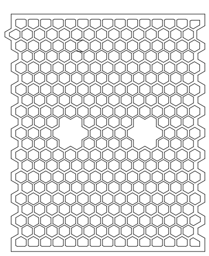

Figure 6: Honeycomb clay brick from Rimmele (λ = 0.12 W/mK)

[31] Honeycomb clay bricks had been produced since the 1940s, but with void sizes similar to those of perforated bricks.

[32] Finite element calculation by the Federal Institute for Materials Research & Testing. Contrary to this, a λ value of 0.13 W/mK is specified in DBU 1996, pp. 4, 21, 27.

[33] DIBt approval Nos. Z-17.1-527, Z-17.1-528, Z-17.1-554, Z-17.1-555, all issued on 3 Dec 1997.

2000–2013: STATE OF THE ART IN THE APPROVALS SYSTEM

Approvals as a bridge between patents and standards

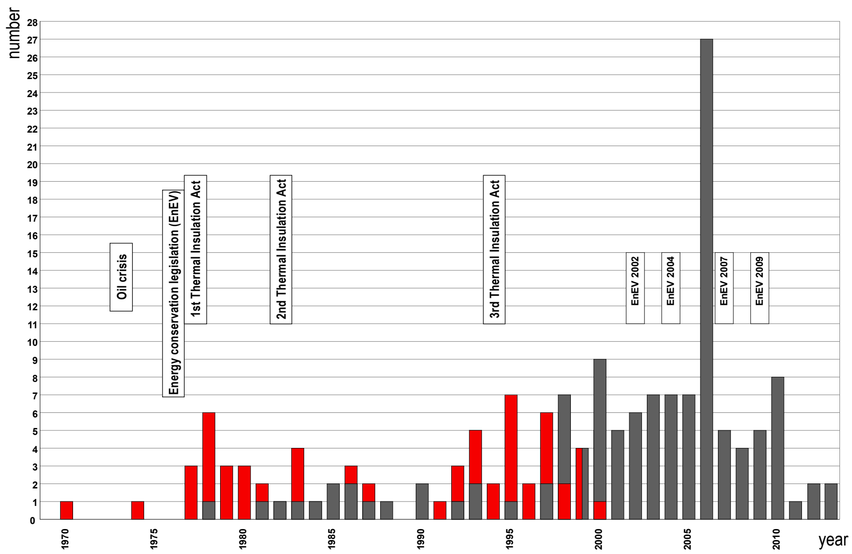

Figure 7: Number of National Technical Approvals over the years 1969–2013 compared with the patents, patent applications and utility models (all shown in red) for the same period

From 2000 onwards we see a significant increase in the number of approvals. Whereas between 1969 and 1999 there were 1.5 approvals annually on average, that number now rose to six.[34] In 2006 alone, some 27 clay bricks were approved. At the same time, the number of patents declined. This allows us to conclude that technical innovations – which would qualify for a patent in the meaning of cl. 1 of Germany's patent legislation – based on the research into insulating clay bricks are hardly possible any more.

Energy conservation legislation provides new incentive for innovation

Germany's three thermal insulation acts of 1977, 1982 and 1994 were followed from 2002 onwards by several energy conservation acts (EnEV), which reduced the maximum thermal transmittance values even further.[35] The thermal insulation and heating system acts were amalgamated in the energy conservation legislation so the total energy efficiency of a building could be considered.

The patent for a gauged brick with a high thermal insulation value ($\lambda = 0.13$ W/mK), which was also granted a National Technical Approval in 1997,[36] could also meet the requirements of

[34] Own evaluation according to information provided by Fraunhofer IRB at http://www.irb.fraunhofer.de/bzp/.
[35] See *Energieeinsparverordnung* 2002, 2004, 2007 and 2009.
[36] DIBt approval ZI-17.1-528, 3 Dec 1997.

EnEV up until 2007. However, in 2007 the clay bricks industry developed a clay brick with a λ value of 0.08 W/mK – a value below that required by EnEV 2007.[37]

State of the art and "end of the art"

Following 2006, the "record year" with 27 approvals, from 2011 onwards only between one and two approvals were issued each year. A decrease in the λ value from 0.08 W/mK to 0.075 W/mK in one year requires seven years of development.[38] In a 36.5 cm thick wall, this clay brick achieves a U value of 0.21 W/m^2K and was approved in 2013. So it complies with the requirements of EnEV 2009, which is still valid.[39] It also satisfies the requirements of the forthcoming EnEV 2016,[40] which calls for a U value of exactly 0.21 W/m^2K.

Both the long development time of seven years for improving the λ value and the low number of approvals with this value allow us to conclude that further improvements are hardly possible.[41]

37 DIBt approval ZI-17.1-972, 31 Mar 2006. The corresponding U value for a 36.5 cm thick wall is 0.22 W/m^2K; 0.35 W/m^2K would be required.

38 DIBt approval Z-17.1-1077, 10 Jan 2013.

39 A U value of 0.28 W/m^2K is required.

40 *Federal Gazette* , vol. 2013, pt. I, No. 67, Bonn, 21 Nov 2013, reference building table: "The annual primary energy requirement of the reference building in lines 1.1 to 8 calculated according to one of the methods given in No. 2.1 is to be multiplied by a factor of 0.75 for new construction work from 1 January 2016."

41 This was confirmed by representatives from the clay bricks industry and clay bricks research: Dr. Figge (Ziegelzentrum Nord) in a conversation on 3 Jun 2013; Dr. Knüpfer (Brick & Tile Research Institute, Essen) in a telephone conversation on 9 Jul 2013.