DESK RESEARCH ON DURABILITY OF INSULATION PRODUCT

Final report

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Introduction

Durability is the ability of a product to maintain its required performance over working life time under normal conditions of use (see guidance paper F)

This means for thermal insulation products that a properly designed and executed work fulfils all requirements for the intended application over an economical reasonable life time.

This economical reasonable life time can vary due to the application between 5 and about 100 years.

The desk research project was made by screening common available literature in English, German and French.

The following product properties were examined for the different insulation materials:

- Thermal conductivity in dry and wet state
- Compressive stress
- Compressive creep
- Humidity and water absorption
- Thickness and Dimensional stability
- Other properties
- Durability and working life studies for different materials

Only respectable and traceable literature sources were used. Private opinions and companies philosophies were avoided where ever possible.

The literature was scanned carefully to avoid wrong values or unacceptable positive or negative characteristics.

No product damages or changes in case of poor workman ship or failure of other building components were examined.

The results of the literature screening were shown in different tables for every property.

For every text, table or figure an index number was created where the first digit represents the literature source and the second digit the number of the document within the source.

1 Definition of Durability and general product description

During the last years issues like durability and working life performance are becoming more and more important. On the one hand customers' interest in thermal insulation products is rising due to the rise of costs for energy, the uncertain security of energy supply as well as the climate change. On the other hand politicians focus more and more on issues like energy efficiency, reduction of CO_2 and last but not least the reduction of foreign energy dependency.

More and more building authorities, but also investors and building owner are asking for information about the constancy or the change over time of declared properties of special thermal insulation products. Furthermore the anticipated utilisation period and the return on invest is important for many customers and investors. Against this background there is no specification or fixing about the durability of a thermal insulation product for a certain application.

Lifetime / working time / working life product

In the guidance paper F of the European Commission from December 2004 a description of "working life" can be found. The "working life" of a thermal insulation product is described as the period in which a complete building component like e.g. a façade with all its fixings, connections and plasters keep their specific essential requirements and properties. The second item which is mentioned in the paper F is the "working life product". This means the period of time in which a component of a façade (e.g.), in this context for example the thermal insulation product, complies with the minimal required performance level without needing mentionable payments for reparation or replacement. (Only costs for the maintenance incurred)

This definition separates clearly between the working life of a complete construction element like a façade or a roof and its components like the thermal insulation (working life product). Unfortunately there are numerous influencing factors like the architectural planning, the clime zone of the building, the building construction itself and also the maintenance of the construction element which are all out of the sphere of influence of a manufacturer of thermal insulation product. Therefore it is not possible to equate a working life of a product or a construction work with a guarantee of a specific component by its manufacturer (see guidance paper F).

All in all a long-run behaviour of a thermal insulation product is specified much more realisable by the item "Durability". The European technical standards EN 13162 (Mineral wool) till EN 13171 (Wood fibre) are going to specify only partly the issue of durability in its revised version (formal vote about 2011/12) and even there is no standardised definition mentioned. Therefore some experienced data from the FIW München as well as from the "Leitfaden nachhaltiges Bauen" [2] concerning the lifetime of thermal insulation products are summarised in the following table. The large spread of the shown data is due to the different building constructions and the functional stress of the individual component as well as the used material.

Lifetime of construction elements with thermal insulation		
construction elements	**years**	**average (years)**
Thermal insulation (flat roof / warm roof)	30 – 60	45
steep roof	40 – 60	50
inverted roof	40 - 60	50
ceiling, floor	30 – 100	65
external insulation to wall, behind cladding	30 – 60	45
ETICS	30 – 50	40
Cavity insulation to double-leaf walls	30 – 60	45
External thermal basement insulation below ground floor slab in contact with the soil	50 – 100	75
External thermal insulation to walls in contact with the soil (perimeter)	30 – 100	65
Insulation of technical equipment of buildings	5 – 25	15

source: Leitfaden nachhaltiges Bauen [2], documentation of manufacturers, experienced data of the FIW München.

The Index of the annex and the texts, tables and figures of the chapter "1 Definition of Durability and general product description" can be found at page 26 ff.

2 THERMAL CONDUCTIVITY

There are existing a lot of measured values of insulation materials in the status after manufacturing. The manufacturer has to measure this data according to the product standards and also a lot of third party measurement of independent testing bodies are existing.

For the cellular plastic materials with closed cells e. g. extruded polystyrene foam (XPS), Polyurethane foam (PUR) and Phenolic foam (PF) the manufacturer are in obligation to determine also aged values of thermal conductivity according to annex C of the European product standards EN 13164 (XPS), EN 13165 (PUR) and EN 13166 (PF). Therefore existing also a lot of data for this accelerated ageing methods.

FIW has screened literature to find also aged values of the thermal conductivity for different insulation materials. During the screening we found very few literature of aged value to show the durability of thermal insulation materials.

The literature was divided into three parts:

A: Thermal conductivity of dry boards after lab storage or reinstalling them out of buildings and drying them.

There were found only values for EPS and XPS.

<u>EPS</u>

For EPS there are existing values after 5 years storage under lab conditions, after 3 to 35 years installation in buildings and after additional artificial ageing which should represent 45 years and after 31 years installation in a real building. No significant change in thermal conductivity was determined in all these studies.

XPS

For XPS there are existing also values for products which were installed in buildings. But these thermal conductivity values were influenced by gas exchange of the blowing agent.

B: Aged values of thermal conductivity versus gas diffusion:

PUR

There are existing values for CFC blown foams at lab conditions over 30 years. For pentane and HCFC 141b blown foams existing curves over 10 years.
All these curves show that the fixed increments are fitting natural ageing over longer times and the Design values of thermal conductivity are realistic.

XPS

Aged thermal conductivity values of XPS are published for CFC blown foams. For CO2 blown foams is ageing is no problem because CO2 diffuses out very quickly and after 90 days to approximately one year the gas exchange is finished.
For HFC blown foams or foams blown with CO2 and Isobutane or Dimethylether, there existing data but they are not published.

Phenolic foam (PF)

For Phenolic foam there are existing data over some years ageing at room temperature and 70 °C ageing for CFC- and Chlorpropane / Pentane blown foams, but these values are not published as far the authors know. There was only one reference found.

Vacuum Insulation Paneels

There are existing curves of ageing at 23 °C and 80 °C-ageing over about 2 years for the extrapolation of the thermal conductivity over 10 years to 25 years. Also some boards from real buildings were tested and for times of 2 to 3 years good correlation with lab measurements were shown.

C: Influence of Humidity and samples out of real buildings:

FIW München found some curves "Thermal conductivity versus Humidity".

Mineral wool:

For mineral wool there existing curves with a linear relation and with a steep slope of the curve lambda versus humidity content, dependend if mass transport occurred or not. The discussion about this is not finished yet.

PUR, EPS, XPS

Also for these materials existing values (see EN ISO 10456) of thermal conductivity versus humidity content.

Alternate insulation materials:

For these materials existing measured values for the water absorption at 23 °C and 80% relative humidity and the increase of thermal conductivity. The insulation products out of organic vegetable and animal fibre materials show a water absorption at this climate 23°C/80% of 13 to 25 m-% and an increase of thermal conductivity of 1 to 7 %.

Samples out of real buildings

In this field existing mainly data for XPS-foam. For the application "Perimeter" and "Inverted roof" a lot of data can be found in the literature of the XPS manufacturers over time periods of 3 to 32 years. The published data show only a small increase of thermal conductivity and water absorption over these long time periods.

The Index of the annex and the texts, tables and figures of the chapter "2 THERMAL CONDUCTIVITY " can be found at page 31 ff.

3 COMPRESSIVE STRENGTH /COMPRESSIVE STRESS

Introduction

Compressive tests according EN 826 are tests which were made in the laboratory of the manufacturer or at a testing laboratory to characterize the mechanical properties of an insulation material.

The test specimen, mostly a cube with the same dimensions as the thickness of the tested boards, will be put between two rigid steel plates and the test specimen is compressed till 10 % decrease of the original thickness is reached (the result is the compressive stress at 10 % deformation) or if the test specimen breaks at a deformation less than 10 % (yield point: the result is the compressive stress at x % deformation). The result of the compressive strength or compressive stress is a short term measured value in a lab (laboratory value) to characterize a material and compare a material with the specification. The compressive strength at yield point or stress at 10 % deformation is **not** a value for the practical application, because in an application the insulation material shall not break or settle more than 2 or 3 %.

Due to influences to the compressive behaviour like time, humidity cellgas exchange, temperature, static and dynamic loads and so on the compressive strength/stress has to be reduced by realistic safety values. Related to the application only 10 % to 40 % of the short term compressive stress can be calculated as a long term compressive stress. In some cases like dynamic load, temperature- and humidity-infuences the long term compressive stress has to be further reduced.

To determine the maximum load or long term compressive stress it is very helpful to determine compressive creep values (next chapter) and the durability of insulation materials by lab tests and by reconstructed samples out of real buildings.

Short term values of compressive-strength/-stress

Every manufacturer of insulation materials is obligated to test regulary the compressive properties of his materials. Therefore for this short term values existing a hugh amount of data. In some cases the compressive properties are dependent on chemical processes like cross linking or chemically combined water or to physical processes like gas exchange or hardening. In these cases the manufacturer has to

determine these effects and related to this to cure the material till delivery to a construction site.

Long term values of compressive-strength/-stress

Also for this property there are only note worthly data for the cellular plastics like EPS, XPS and PUR are available.

EPS

For EPS there are some values are available for EPS samples out of buildings for 2 to 35 years (fig. 06-03 EPS and 37-04 EPS). This figures show no remarkable decrease in compressive properties over the time.

XPS

In the case of XPS there are existing a lot of data of reconstructed samples which were installed in buildings over 7 to 32 years (see fig. 08-01 XPS to 38-02 XPS). The samples were tested in a wet shape and sometimes also dried. All published data are above the nominal value with a tendency to higher values depending of time.

PUR

Polyurethane (PUR) Foam was also stored over long times under lab conditions. For CFC-blown foams there exists a study over 15 years (fig. 13-03 PUR) which shows an increase of compressive strength/-stress over the time. Also for the new blowing agents like pentane was an increase of compressive strength detected but not systematically determined and published. First results see table 48 and 49)

The Index of the annex and the texts, tables and figures of the chapter "3 COMPRESSIVE STRENGTH/COMPRESSIVE STRESS" can be found at page 89ff.

4 COMPRESSIVE CREEP

The method to determine the long term behaviour of a thermal insulation product under compressive stress is the compressive creep test according to EN 1606.
For the compressive creep test a test specimen in shape of a cube is placed between two rigid steel plates and a load is pressing the insulation cube permanently.

The decrease in thickness is measured and plotted versus time. Due to the theory of "Findley" the measured value can be extrapolated over a logarithmic time scale by a factor of 30. This means to predict a 10 years compressive creep value the test specimen have to be tested over a time of 122 days and to extrapolated by the factor 30. For a intended use of 50 years the test specimens have to be tested 608 days or 1,67 years.

The results of the creep tests have to be reduced if additional dynamic loads, temperature or humidity influence the insulation in practise. Very limited knowledge exists about these influences.

In most cases only deformation of maximal 2 % are accepted because of the thermal resistance or in the connection of other building materials.

During the screening of literature only creep values for the cellular plastics EPS, XPS and PUR were found.

<u>EPS</u>
For EPS boards existing a lot of data for different types e.g. sound insulation with a density of 8,6 kg/m³ to 12 kg/m³ and loads of 2 to 5 kPa under floors over 2 years testing time (see fig. 05-02 EPS and 05-03 EPS).

For EPS with higher density existing data for 2 years to approximately 9 years under different loads (see fig. 21-01 EPS to 32-02 EPS).

XPS

Also for XPS existing a lot of curves deformation versus time for testing times of 1 to 7 years and loads of 80 kPa to 450 kPa (see fig. 20-01 XPS to 20-06 XPS).
Also some figures under dynamic loadings are available (see fig. 20-4 XPS).

PUR

In the literature existing very few creep values about PUR foam. Only two curves were found for different PUR-products with 33 kg/m³ and 80 kg/m³ density and loads of 40 kPa and 200 kPa over a time of 5 years (see fig. 12-01 PUR and 12-02 PUR).

The Index of the annex and the texts, tables and figures of the chapter "4 COMPRESSIVE CREEP" can be found at page 121 ff.

5 HUMIDITY AND WATER ABSORPTION

The chapter 5 is divided in humidity and water absorption. In principle, any type of water absorption is undesirable for any type of thermal insulation product, because the increase of humidity always causes an increase of the thermal conductivity. Furthermore the absorption of water affects other properties of the insulation material like compressive stress or compressive creep, too.

During the literature research, there has been found some information about the insulation materials mineral wool, EPS, XPS, PUR, WW and about not standardised, alternate insulation materials.

Mineral wool

Concerning the mineral wool, a correlation between humidity and the thermal conductivity is mentioned. According to DIN prEN12524 a correlation factor for humidity for different thermal insulation products can be chosen to calculate the thermal conductivity of a humid material. (44-01 and 44-04). Unfortunately there could not be found any measurements of aged boards or of boards which have been removed from a façade or roof. The information about loose mineral wool and EPS are very rare, only a approximate value of the humidity in mass-% after storage at 23°C / 80% has been found.

EPS

Concerning EPS, there is an older figure showing the water absorption during 25 days. In this sample (37-03) the Vol-% of a 31 years old EPS is about 0,02% (mean value out of 5 measurements).

XPS

For the XPS products there are once more mentioned the reports of the removed boards from different projects of the DOW company from 5 till 32 years. The found test results for the humidity of XPS boards range between 1 to 5 Vol-%, obviously not depending on the different age or the individual application.

PUR

About thermal insulation products made of Polyurethane (PUR) the increase of humidity in time (concerning the absorption by immersion) and a correlation between humidity and thermal conductivity of PUR foam are listed at page 39 to 41. As a result: The rise of the humidity of e.g. PUR boards is listed from 0% up to 1,3% Vol-% cause the rise of the thermal conductivity from 0,027 W/mK up to approximately 0,028 W/mK.(blowing agent pentane, thickness 60mm, density 35,4kg/m³).

Information about the humidity of different thermal insulation products are shown in the last chapter. Figure 44-01 and 44-04 shows once more the correlation factor for humidity as well as the correlation and correction of the thermal conductivity for other thermal insulation materials like expanded or extruded polystyrene, PUR, foam glass and wood wool products, too.

alternate insulation

The influence of water absorption of alternate insulation products are described in 43-02. The humidity of different types of material in mass-% (43-03) inside such a thermal insulation products rises the thermal conductivity between 1% and 7%. (Water vapour transport) This is illustrated with the special structure of alternate insulation products, which are mainly made out of organic fibres. Another table (44-03) shows the water absorption in mass-% of different thermal insulation materials.

No results have been found for :

Foam glass, EPB, ICB, Wood fibre, VIP

The Index of the annex and the texts, tables and figures of the chapter "5 HUMIDITY AND WATER ABSORPTION" can be found at page 141 ff.

6 THICKNESS AND DIMENSIONAL STABILITY

The thickness and the dimensional stability are the key properties for the field installation in a building. The thickness has the same importance as the thermal conductivity for the thermal resistance. The thermal resistance is the measure of the effectiveness of an insulation layer. The appearance of thermal bridges in a façade, e.g., or the dishing of boards are some examples for the influence of the property "dimensional stability".

The chapter 6 includes mainly only two materials, EPS and PUR.

EPS

At first figure 26-02 shows a figure about the shrinkage of EPS boards with a thickness of 40mm. Unfortunately this figure is more than 20 years old, but it shows a small, but typical shrinkage of EPS within the first 1-2 years. In this case the shrinkage range is between 0.32% for EPS products with a density of 15 kg/m³ and approximately 0.5% with a density of 25kg/m³. As expected the products with a lower density have finished this procedure earlier (15kg/m³ after approx. 10 month) than products with a higher density (after approx. 21 month). This example shows only the effect on boards with a thickness of 40mm. These days products made of EPS are much more thicker, but for this issue, no facts was found. Due to improvement of EPS raw material the shrinkage is lower for modern EPS types, but still existing.

Results of measurements under load and temperature (combination 20kPa/80°C and 40kPa/70°C) of 31 years old EPS boards of the type "WD" and "WS" can be found at figure 37-05 and 37-06 according to DIN 18164. (type "WD" at 20kPa/80°C (DLT1) density 19kg/m³ deformation 9% / type "WS" at 40kPa/70°C (DLT2) density 20kg/m³ deformation 31%)

PUR

Within 15 years of storage at 23°C/50%rH different types of PUR boards have been measured under load and temperature of 20kPa at 80°C (time 48 hours). The results can be found in figure 13-04. The figure shows that there is no trend observable concerning the modification of thickness of PUR boards in correlation with its individual age.

Concerning the alternate and all the other standardised thermal insulation materials there can be no published test result found for the change of thickness over time, neither for settling of loose fill nor for the dimensional stability of a built-in or measured product.

No results have been found for :

Mineral wool, XPS, Phenolic foam, Foam glass, wood wool, EPB, ICB, Wood fibre, VIP

The Index of the annex and the texts, tables and figures of the chapter "6 THICKNESS AND DIMENSIONAL STABILITY" can be found at page 185 ff.

7 Other Properties

Mineral wool / EPS

The list „other properties"starts with a documentation between 12 different types of "ETICS-" façades (figure 15-01 till 15-04). As a thermal insulation, mineral wool or EPS has been built-in in different thickness. The documentation shows the individual inspection as well as the refurbishment the done maintenance on the façade as well as the status of the facade. The range of thickness is 60mm for mineral wool and between 20mm and 60mm for EPS material and was built-in between 1969 and 1986. The end of the test is 2004.

EPS

Measurement of bending strength on 35 years old EPS boards can be found in figure 06-05.

The figure shows the age of a product over the measured bending stress normalised of a density of 25 kg/m³, the data for measurement inaccuracy included.

Furthermore results of a measurement of puncture according EN 388 - ISO 12236 a 35 years old EPS board is shown in 06-04. As a function of age over "puncture load", there is also no trend noticeable.

A few information about the fire resistance of aged EPS samples as well as the resistance against microorganism, UV and mildew finish the information about EPS.

XPS

Concerning XPS there are some test reports of closed cell structure on aged XPS plates (7-18 years) in this register. The measured values for closed cell structure of 7-18 years old XPS insulation products is between 93% and 98%.

PF

Some information about Phenolic thermal Insulation products concerning the Durability and resistance to Solvents, Fungi and Rodents can be found in text 40-01 and 40-02.

Vacuum-Insulation Panels (VIP)

Apart from a technical data sheet of Foam glass and a picture of EPB perlite there have been found also some documentation about vacuum-insulation-panels. Subjects like the stabilisation and the change of the air pressure inside the panel over time are mentioned, but also indirect criteria for a description of the vacuum can be found, like e.g the rise of mass of a panel over time. According to figure 14-01, the average rise of the pressure inside a vacuum panel is about 0.7 mbar/a (measured over 3 years). Furthermore the report shows also a linear correlation from the rise of the pressure inside the panel over time. Within 15 years the rise of the thermal conductivity of a vacuum- insulation panel is expected to be approximately $0{,}3 \times 10^{-3}$ W/mK . In the same report another project is mentioned: "Messprojekt Flachdach Regensdorf". In this project the rise of the pressure inside a VIP is measured with 1,5 mbar/a and the extrapolated thermal conductivity after 25 years is calculated to be $7{,}6 \times 10^{-3}$ W/mK. Furthermore the change of the mass of a panel is mentioned in the report of the ZAE. The data are used to predict aged value of thermal conductivity over the predicted life time of 25 years.

No or very less results have been found for:

PUR, wood wool, ICB and wood fibre

The Index of the annex and the texts, tables and figures of the chapter "7 Other Properties" can be found at page 190 ff.

Found product characteristics according to the EN- standards 13162 to 13171, VIPs and others

Desk Research, May 2010

		chapter 2 Thermal conductivity			chapter 3	chapter 4	chapter 5	chapter 6	chapter 7
		A dry / dried boards	B gas diffusion	C humid boards	Compressive stress	Compressive creep	Humidity / water absorption	Thickness / Dimensional stability	Other Properties
EN 13162	MW			x			x		x
EN 13163	EPS	x			x	x	x	x	x
EN 13164	XPS	x		x	x	x	x		x
EN 13165	PUR		x	x	x	x	x	x	
EN 13166	PF						X		x
EN 13167	CG								x
EN 13168	WW						x		
EN 13169	EPB								x
EN 13170	ICB								
EN 13171	WF								
-	VIP		x						x
-	Others			x			x	x	x

Conclusion

Regarding the results of this desk research, it is remarkable that there are a lot of uncharted territories (white fields) concerning the properties and the durability of insulation products.

On the one hand there are numerous published measurements of e.g. aged and used products of extruded polystyrene (XPS) concerning the thermal conductivity, humidity or compressive stress after several years; on the other hand no test result of widely-used products or very seldom used products has been found for these properties. Of course it is conceivable that there are existing test results for those properties, but they are neither published by the companies themselves nor by an association of manufacturers like e.g. EURIMA, EUMEPS, EXIBA and so on.

Apart from the products with the highest market shares like MW, EPS, XPS, EPS and PUR there have been no published test result found of thermal conductivity, compressive stress, compressive creep or humidity for the other EN - standardised products as for example PF, WW, EPB, ICB or WF.

For the non- standardised Vacuum- Insulation- Panels VIP it seems that the customers and users of vacuum insulation materials are more and more interested in durability items, especially in the endurance of the vacuum inside the panels and therefore of the thermal conductivity of the whole panel.

Last but not least there is another key property with almost no hits at the desk research: The fire resistance. Not even one test result of a fire test of a few years old und used product was found in a published way. Only the ÜGPU study [50] gives some indications and the EPS white book [25] contains a small comment – but no test results - on this issue.

Overall the subject of "Durability" and of a "working life" of a product with usable properties is not a new trend within the last few years. Over the last 30 – 40 years there are some existing measurements for a small variety of products and properties. But also products and blowing agents changed over the time.

To fill up the uncharted territories it would be certainly necessary to get more measured values of the key properties of all standardised products from EN 13162 to EN 13171 as well as VIPs and the vegetable or animal fibre insulation products. Those possible key properties of at least ten years old products could be:

- Thermal conductivity
- Compressive stress
- Compressive creep
- Humidity
- Water absorption
- Gas diffusion
- Thickness
- Dimensional stability
- Fire resistance

Having such an entire overview a development of the guidance paper F as well as explicit and common criteria could be defined as a standard of durability for each kind of thermal insulation product.

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