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Thermal conductivity measurement of cellular glass samples

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Thermal conductivity measurement of cellular glass samples

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Architectural Engineering

DCE Technical Report No. 263

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Thermal conductivity measurement of
cellular glass samples

by

Hicham Johra

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Contents

Contents	5
1. Introduction.....	6
2. Cellular glass: general information.....	7
3. Cellular glass study cases.....	8
3.1. Glapor®	8
3.2. FOAMGLAS®	8
3.3. CleanTechBlock cellular glass sample.....	8
3.4. CleanTechBlock wall element.....	10
4. Thermal conductivity measurement methods	12
4.1. Guarded Hot Plate Apparatus EP500	12
4.2. Guarded Hot Box setup	14
5. Measurement results	15
5.1. Guarded Hot Plate Apparatus EP500	15
5.1.1. Glapor®	15
5.1.2. FOAMGLAS® W+F	16
5.1.3. FOAMGLAS® T4+.....	17
5.1.4. FOAMGLAS® S3.....	18
5.1.5. FOAMGLAS® F.....	19
5.1.6. CleanTechBlock sample	20
5.2. Guarded Hot Box setup	21
6. Results summary	23
References	27

1. Introduction

The goal of the project CleanTechBlock 2 is to develop and test a durable and sustainable construction wall element which complies with the building regulations of 2020, and has a certain aesthetics attractiveness. The CleanTechBlock (CTB) prefabricated elements consist of cellular glass insulation blocks mounted in between two layers of brick masonry [1] [2].

The aim of this technical document is to report the results of the different experimental investigations performed on the CTB and other commercial cellular glass samples to determine their thermal conductivity. These experimental investigations have been carried out at the Laboratory of Building Energy and Indoor Environment at the Department of Civil Engineering of Aalborg University (Denmark).

These experimental investigations have been financially supported by the EUDP project EUDP 15-I, CleanTechBlock II – energibesparende facadebeklædning, J.nr. 64015-0018 [1] [2].

2. Cellular glass: general information

Cellular glass is an inorganic porous glass foam material. It is fabricated from pulverized, crushed or granulated glass mixed together with a chemical foaming agent such as carbon or limestone. The mixture is heated up in a cellulating furnace at around 1000 °C, below the melting temperature of the glass (which is usually around 1200 °C) to avoid any collapsing of the glass foam. At that temperature, the foaming agent releases a gas inducing a foaming effect in the glass and the formation of numerous small-scale pores. After cooling, the cellular glass hardens into a rigid low-density material with gas-filled closed-cell pores.

Cellular glass is a very good insulation material with remarkable properties:

- Low thermal conductivity
- Moisture resistant with a zero-water permeability
- Not subjected to corrosion
- Long term durability and chemical stability (no aging effect)
- Does not release flammable liquids or gas at high temperatures
- Non-flammable, non-combustible, no smoke release
- High compressive strength
- Wide temperature service range
- Dimensionally stable

Because of these appreciable properties, cellular glass is widely used in numerous applications:

- Building wall insulation
- Green roof insulation
- Fireproof building panels
- Chemical and oil industry
- Ethylene plant pipes and equipment
- Machine room noise reduction
- Road sound absorption barrier
- Underground steam distribution

3. Cellular glass study cases

In this experimental study, several commercial cellular glass samples have been tested together with the CTB cellular glass product and the CTB wall element (including 2 layers of brick masonry). A description of the different study cases can be found hereafter.

3.1. Glapor®

The Glapor® cellular glass is produced directly from waste flint glass with glycerol foaming agent and water glass additive. The Glapor® manufacturing process has a smaller ecological footprint and a lower cost. However, Glapor® cellular glass typically presents insulation properties which are inferior to other commercial cellular glass products (see *Table 1*) [3].

3.2. FOAMGLAS®

FOAMGLAS® cellular glass is prepared from glass with adjusted composition: re-melted recycled glass and natural abundant minerals such as sand, dolomite or lime. Carbon black is used as foaming agent. A reducing atmosphere is applied in the furnace to prevent the carbon from burning before the glass sinters. Several grades of products are produced with this technology with density and thermal conductivity ranging from 100 - 165 kg/m³ and 0.038 – 0.050 W/m K, respectively (see *Table 1*) [4].

Table 1: Commercial products characteristics (manufacturer's data)

Product name	Density [kg/m ³]	Thermal conductivity (10°C) [W/m.K]
FOAMGLAS® W+F	100	0.038
FOAMGLAS® T3+	100	0.036
FOAMGLAS® T4+	115	0.041
FOAMGLAS® S3	130	0.045
FOAMGLAS® F	165	0.05
Glapor®	125	0.054

3.3. CleanTechBlock cellular glass sample

The block of cellular glass in the CleanTechBlock 2 project are manufactured by direct foaming of waste glass material without remelting process (see *Figure 1*). The CTB cellular glass has closed cells filled with CO₂ and containing very little H₂.



Figure 1: CleanTechBlock cellular glass sample

3.4. CleanTechBlock wall element

The CTB wall element is composed of a 45 cm layer of CTB cellular glass blocks mounted in between 2 external layers of brick masonry (see *Figure 2*, *Figure 3* and *Figure 4*). Each external brick layer is 4 cm thick. The thermal conductivity of the bricks has been measured to be 0.576 W/m.K (with Guarded Hot Plate Apparatus EP500).



Figure 2: CleanTechBlock wall element mounted on insulation frame for Guarded Hot Box test.



Figure 3: CleanTechBlock wall element: cellular glass blocks mounted in between 2 external layers of brick masonry [1].

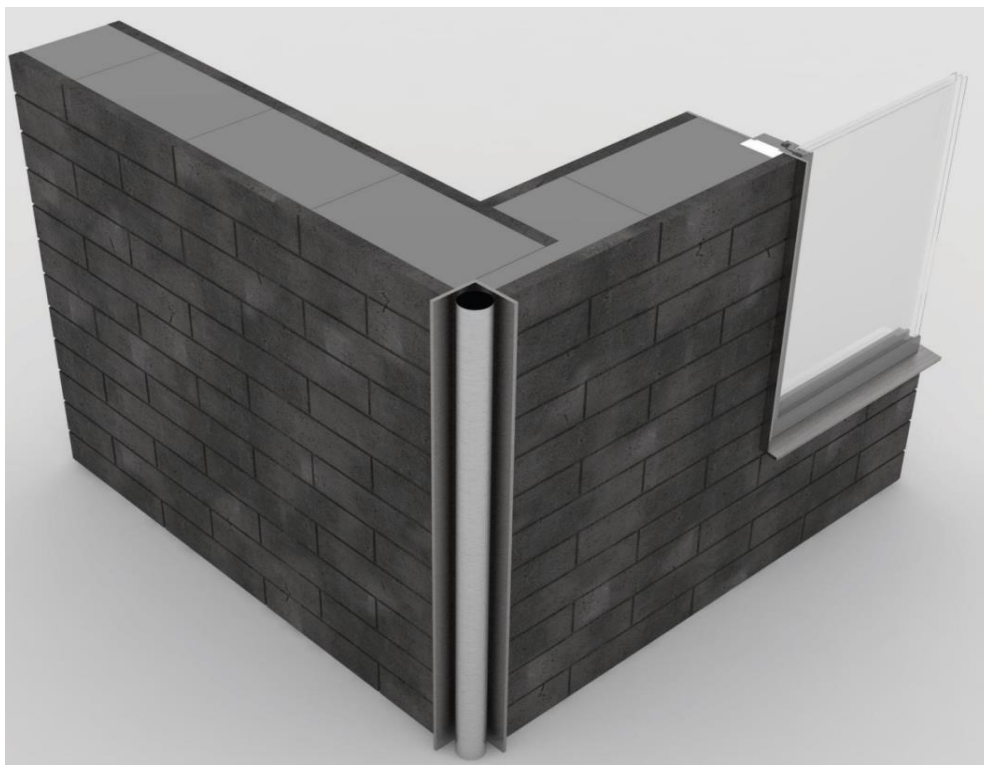


Figure 4: CleanTechBlock wall elements used for the construction of a building [1].

4. Thermal conductivity measurement methods

4.1. Guarded Hot Plate Apparatus EP500

The Guarded Hot Plate Apparatus EP500 is a state-of-the-art instrument for the thermal conductivity measurement of building materials (see *Figure*). It can measure 15 cm x 15 cm squared samples with a thickness ranging from 1 cm to 12 cm. The instrument can measure material thermal conductivities ranging from 0.005 W/m.K to 2 W/m.K for average sample temperatures ranging from 10 °C to 40 °C.



Figure 5: Guarded Hot Plate Apparatus EP500

Thermal conductivity measurements performed by the Guarded Hot Plate apparatus are carried out with steady state temperature boundary conditions. The instrument maintains a one-dimensional temperature gradient between the hot surface plate and a cold surface plate. The temperature of the upper plate, the temperature of the lower plate, the heat flux supplied to the sample and the thickness of the sample are continuously monitored (see *Figure*).

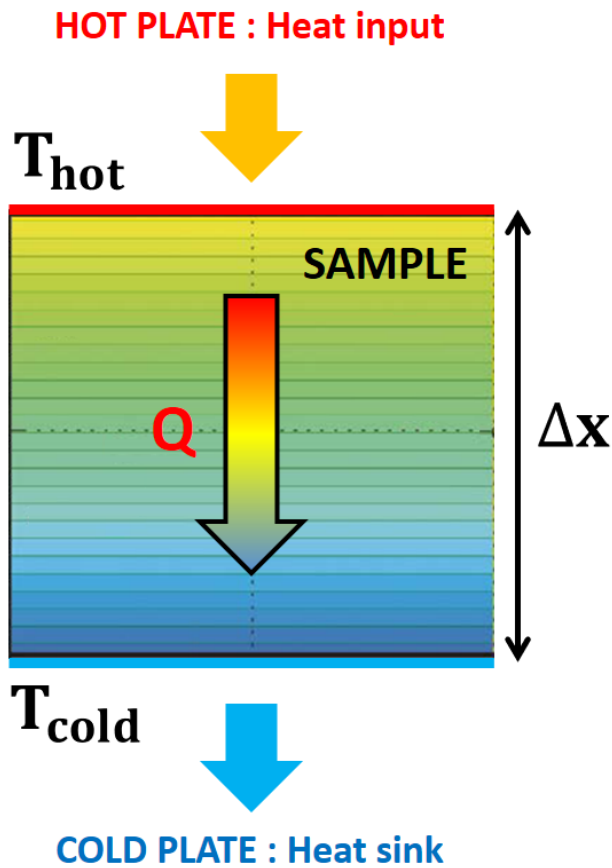


Figure 6: Guarded Hot Plate Apparatus measurement principle

From the Fourier's law of heat transfer by conduction, the material thermal conductivity at a given temperature (average between upper and lower plate temperatures) can be calculated with the following equation:

$$\lambda = Q \frac{\Delta x}{(T_{hot} - T_{cold})A}$$

Where λ , Q , Δx , T_{hot} , T_{cold} and A are the material thermal conductivity, the heat flux through the test sample, the surface temperature on the hot side of the sample, the surface temperature on the cold side of the sample and the surface area of one face of the sample, respectively. When the thermal conductivity measurement is stable (measurement change lower than 0.3% over 600 minutes), the test is completed.

4.2. Guarded Hot Box setup

Similarly to the Guarded Hot Plate Apparatus, the Guarded Hot Box setup is maintaining a steady state one-dimensional temperature gradient between the hot surface and the cold surface of the test sample. The main differences with the Guarded Hot Plate Apparatus are that the tested samples have much larger dimensions (between 1 m and 2 m heights and width) and that the heat transfer is not vertical but horizontal (see *Figure*). Because of the larger size and thus larger thermal inertia of the entire system, the stabilization of the thermal conductivity measurement is much slower. It usually takes about 2 days to reach steady state temperature and heat conditions and 24 hours for the measurement of the thermal conductivity.

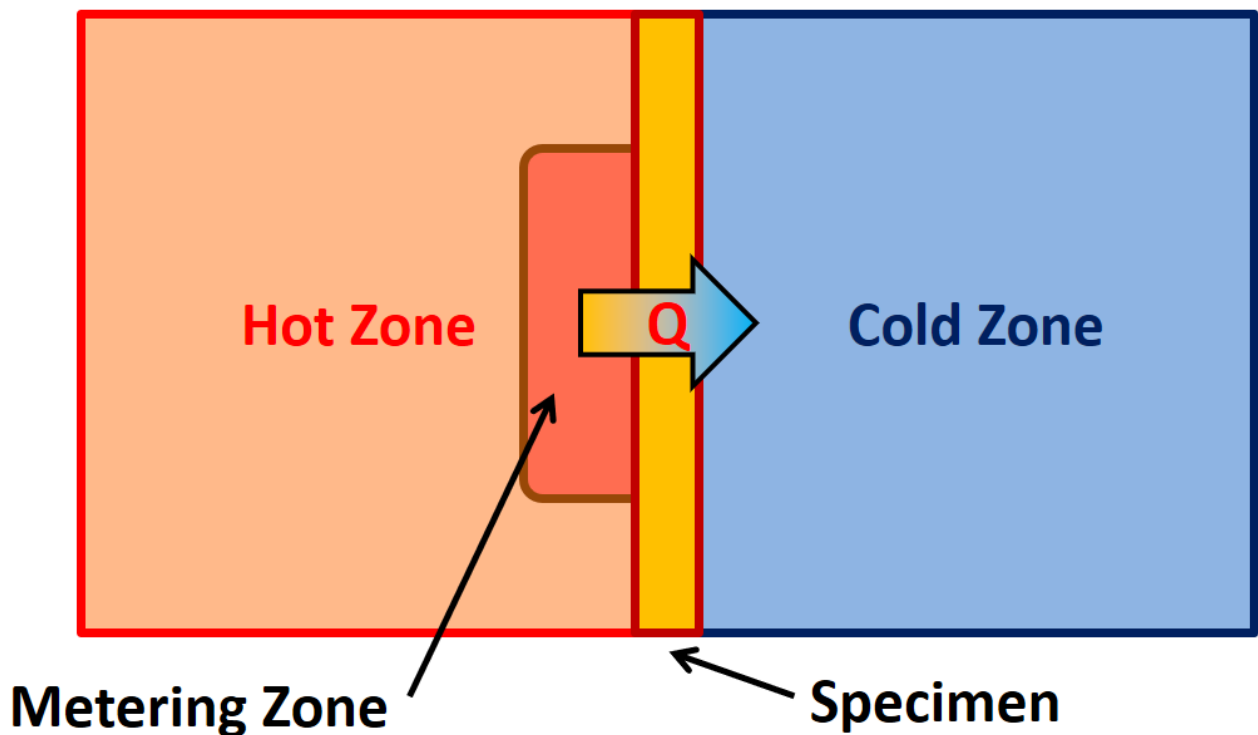


Figure 7: Guarded Hot Box setup measurement principle

5. Measurement results

5.1. Guarded Hot Plate Apparatus EP500

Commercial and CTB cellular glass samples have been tested in the same conditions with the Guarded Hot Plate Apparatus EP500. For the commercial products, the experimental data is compared to the manufacturer's data.

5.1.1. Glapor®

The Glapor® thermal conductivity stated by the manufacturer is assuming that the cellular glass has a density of 125 kg/m^3 . However, the tested Glapor® sample of the current study has a density of 133.5 kg/m^3 . One can see in *Figure* that the Guarded Hot Plate Apparatus EP500 measurements give a slightly higher thermal conductivity than the data provided by the manufacturer. The difference could be explained by the variation of density in between the sample tested by the manufacturer and the sample tested in the current study. Indeed, lowering the density of the cellular glass tends to decrease the thermal conductivity.

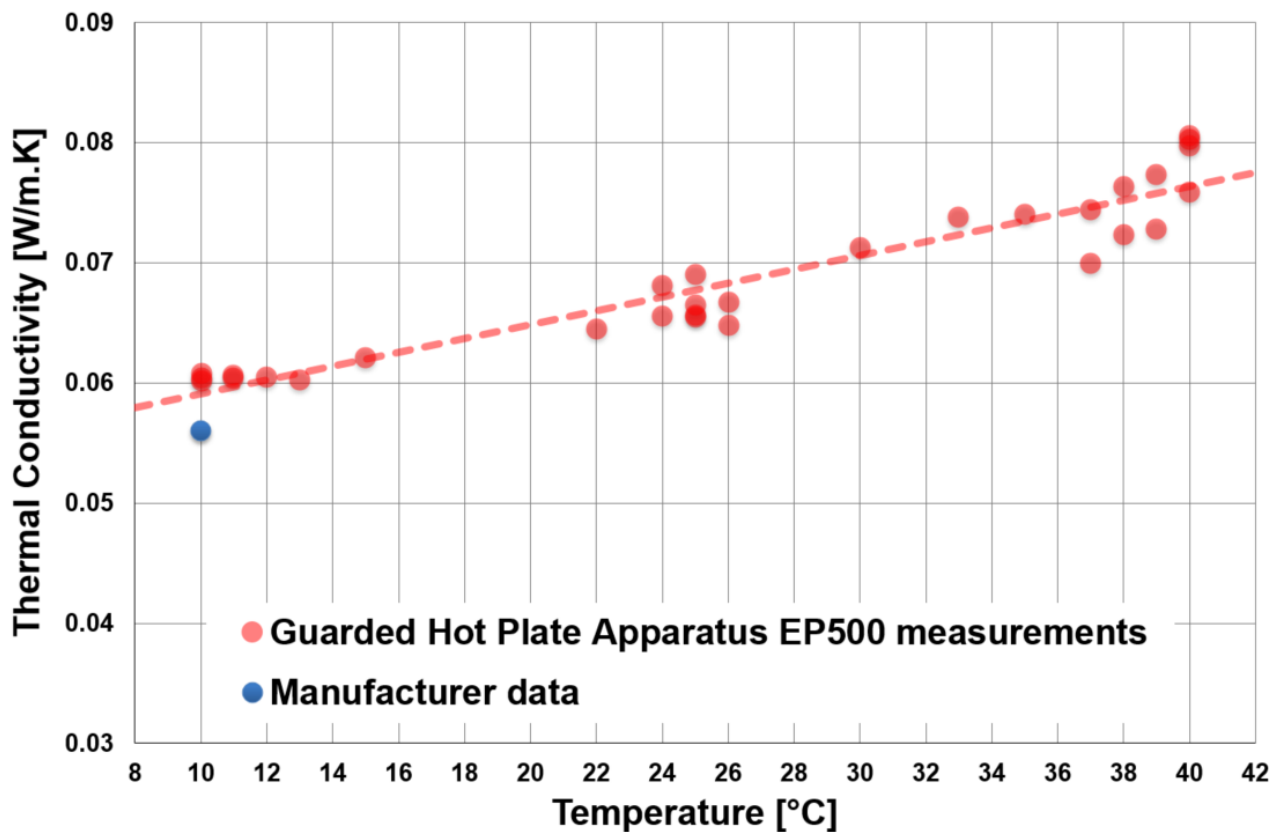


Figure 8: Thermal conductivity of the Glapor® cellular glass as function of temperature

5.1.2. FOAMGLAS® W+F

The FOAMGLAS® W+F thermal conductivity stated by the manufacturer is assuming that the cellular glass has a density of 100 kg/m³. The tested FOAMGLAS® W+F sample of the current study has a density of 94.7 kg/m³, which is close to the manufacturer's statement. One can see in *Figure* that manufacturer's data and measurements from the Guarded Hot Plate Apparatus EP500 are in very good agreement.

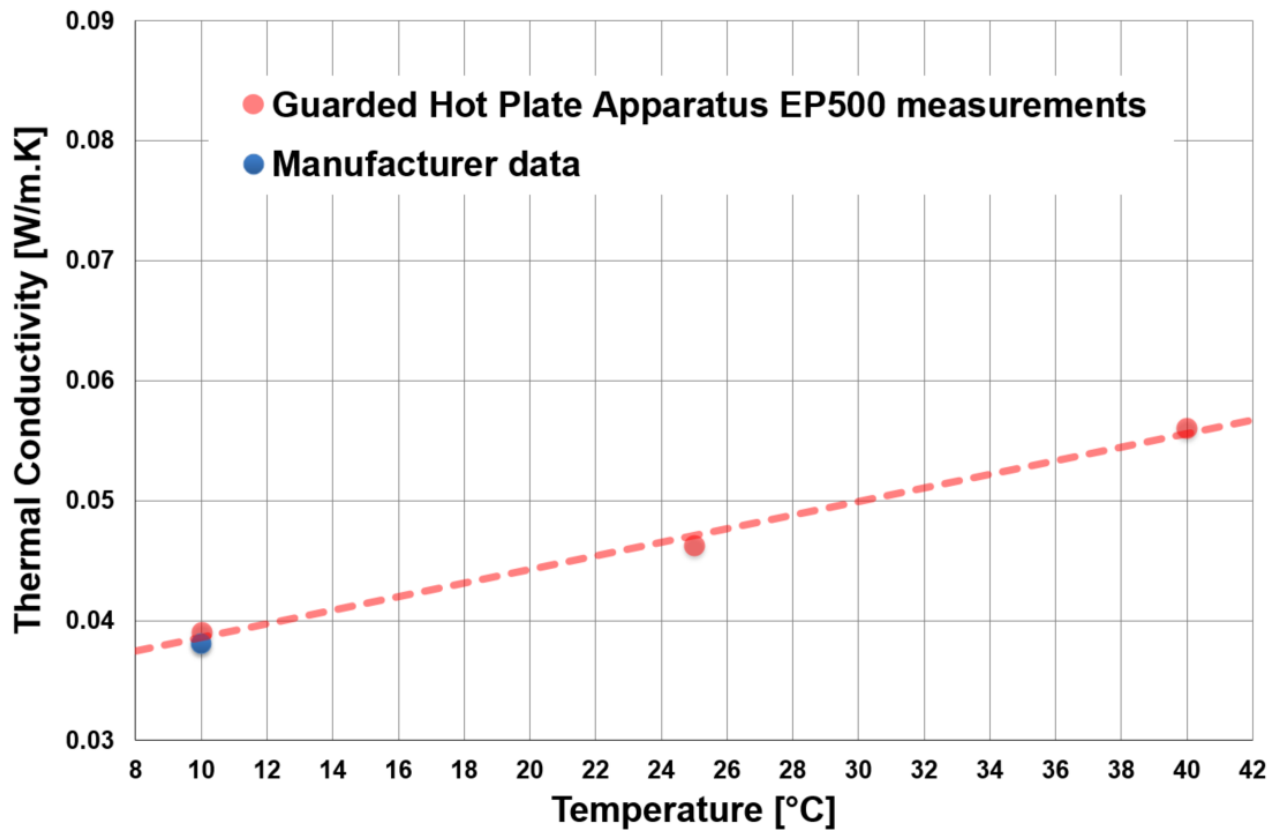


Figure 9: Thermal conductivity of the FOAMGLAS® W+F cellular glass as function of temperature

5.1.3. FOAMGLAS® T4+

The FOAMGLAS® T4+ thermal conductivity stated by the manufacturer is assuming that the cellular glass has a density of 115 kg/m³. The tested FOAMGLAS® T4+ sample of the current study has a density of 112.1 kg/m³, which is close to the manufacturer's statement. One can see in *Figure* that the Guarded Hot Plate Apparatus EP500 measurements give a higher thermal conductivity than the data provided by the manufacturer.

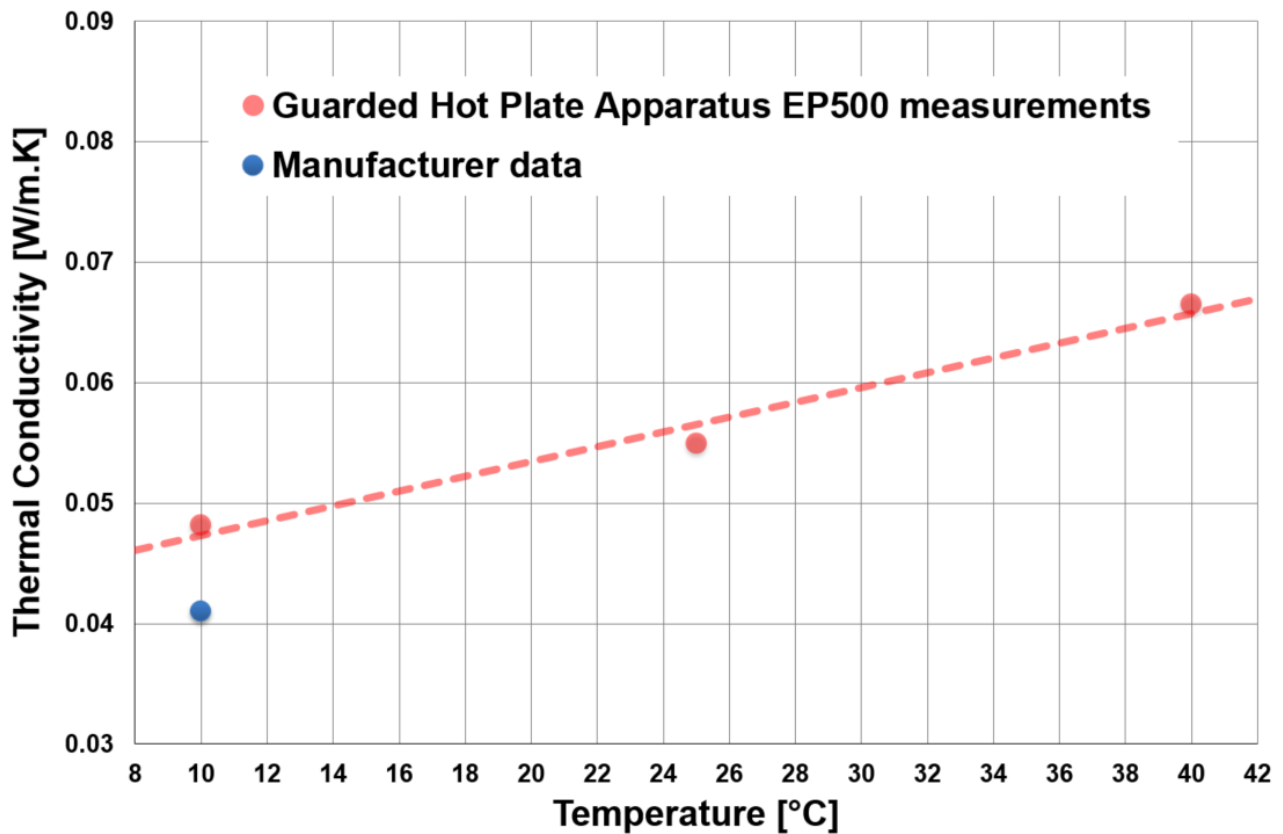


Figure 10: Thermal conductivity of the FOAMGLAS® T4+ cellular glass as function of temperature

5.1.4. FOAMGLAS® S3

The FOAMGLAS® S3 thermal conductivity stated by the manufacturer is assuming that the cellular glass has a density of 130 kg/m³. The tested FOAMGLAS® S3 sample of the current study has a density of 125 kg/m³, which is close to the manufacturer's statement. One can see in *Figure* that the Guarded Hot Plate Apparatus EP500 measurements give a slightly higher thermal conductivity than the data provided by the manufacturer.

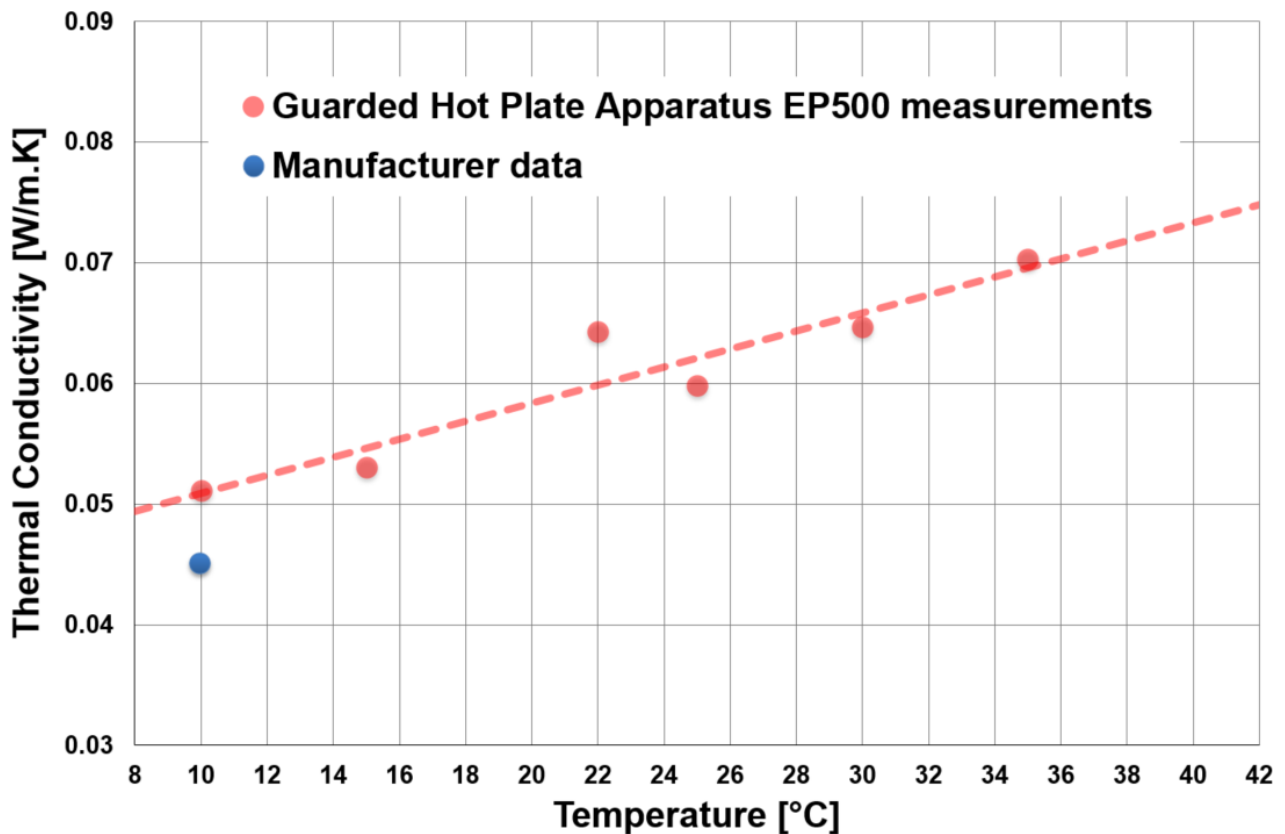


Figure 11: Thermal conductivity of the FOAMGLAS® S3 cellular glass as function of temperature

5.1.5. FOAMGLAS® F

The FOAMGLAS® F thermal conductivity stated by the manufacturer is assuming that the cellular glass has a density of 165 kg/m³. However, the tested FOAMGLAS® F sample of the current study has a density of 175.7 kg/m³. One can see in *Figure Figure* that the Guarded Hot Plate Apparatus EP500 measurements give a higher thermal conductivity than the data provided by the manufacturer. The difference could be explained by the variation of density in between the sample tested by the manufacturer and the sample tested in the current study. Indeed, lowering the density of the cellular glass tends to decrease the thermal conductivity.

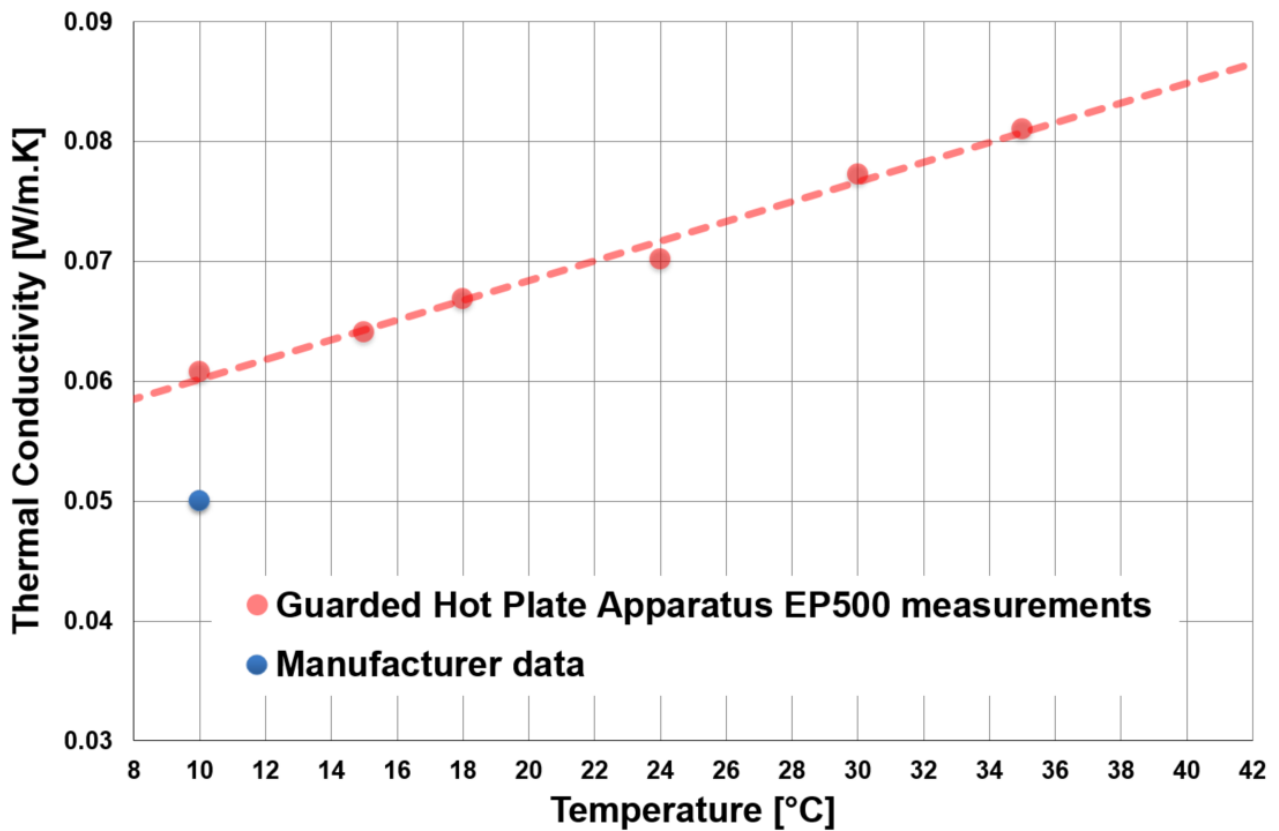


Figure 12: Thermal conductivity of the FOAMGLAS® F cellular glass as function of temperature

5.1.6. CleanTechBlock sample

The tested CTB sample has a density of 132.8 kg/m^3 . Similarly to the other tested cellular glass samples, one can see in *Figure 13* that the thermal conductivity of the CTB cellular glass increases linearly as function of temperature in between 10°C and 40°C .

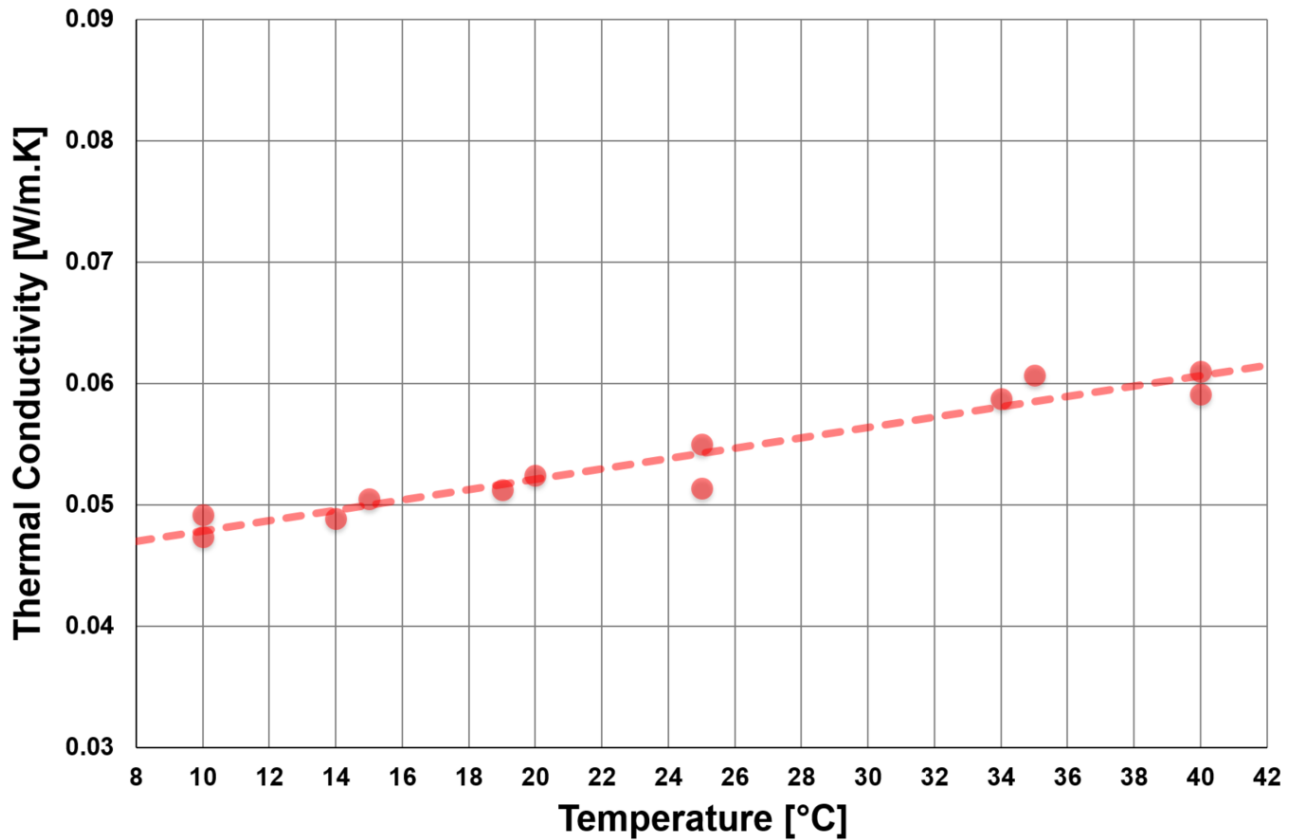


Figure 13: Thermal conductivity of the FOAMGLAS® F cellular glass as function of temperature

A comparison of all Guarded Hot Plate Apparatus EP500 measurements for the CTB sample and the other cellular glass samples is presented in *Figure 14*.

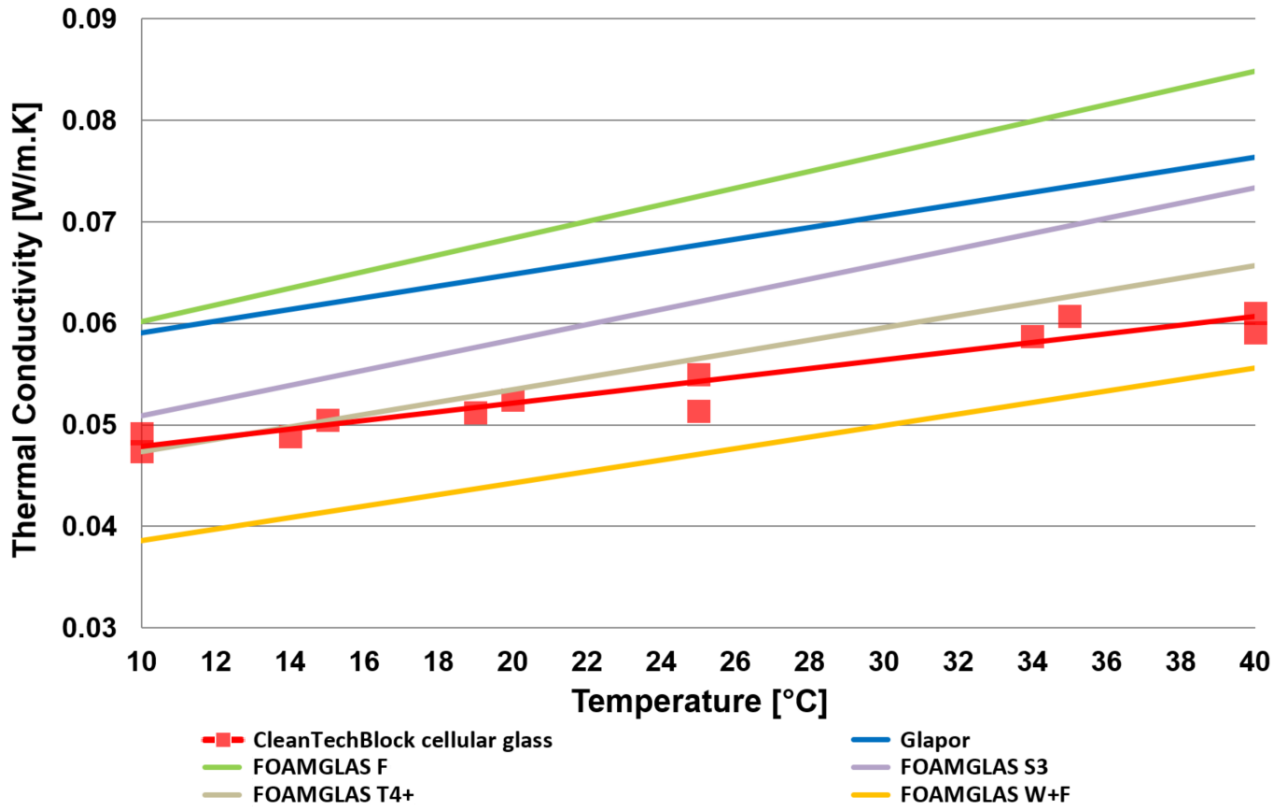


Figure 14: Thermal conductivity measurements (Guarded Hot Plate Apparatus EP500) of the different study cases as function of temperature

5.2. Guarded Hot Box setup

The CTB wall element is tested with the Guarded Hot Box setup. The surface temperature homogeneity, temperature gradient between the cold and hot face of the wall, and the heat flux in the metering zone are monitored during several day in order to insure that steady state conditions have been reached successfully. After around 2 days of stabilisation, the measurements remain stable and the U-value (thermal transmittance) of the entire CTB wall element is measured and averaged over 24 hours. The dimensions of the different material layers of the CTB wall element have been measured precisely, together with the thermal conductivity of the brick masonry layers (Guarded Hot Plate Apparatus EP500). It is therefore possible to calculate the thermal conductivity of the CTB cellular glass which is located in the centre of the CTB wall element. One can see in *Figure* that the equivalent thermal conductivity measured with the Guarded Hot Box is significantly larger than the results from the Guarded Hot Plate Apparatus EP500. This can be explained by the fact that the CTB wall element might contains a number of cracks in between the different cellular glass blocks and in the mortar sealing the bricks. Direct air infiltration through those cracks increases

the heat losses through the wall element resulting in a higher equivalent measured thermal conductivity of the CTB cellular glass material.

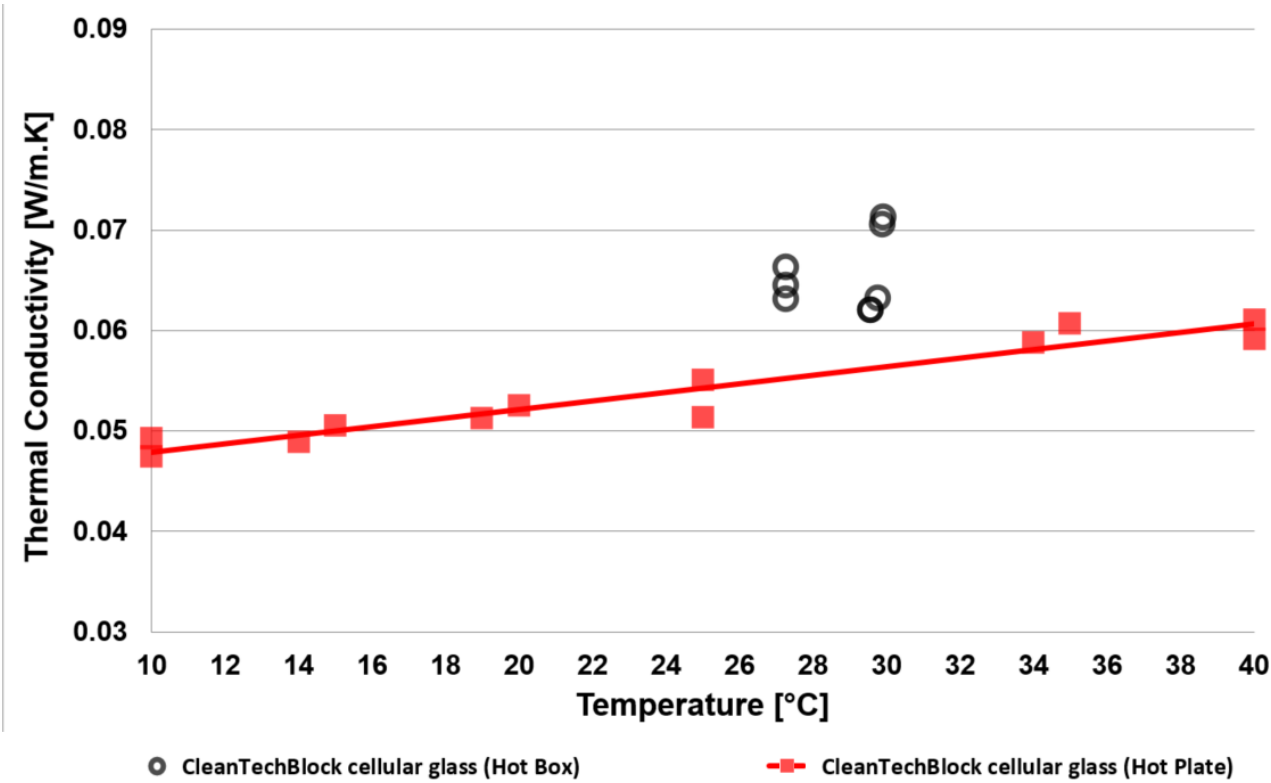


Figure 15: Thermal conductivity of the CleanTechBlock cellular glass: measurements with Guarded Hot Plate Apparatus EP500 and Guarded Hot Box setup

6. Results summary

One can see in *Table* and in *Figure* the summary of the main experimental results of this study. One can observe that the CTB cellular glass has a thermal conductivity which is in between the one of FOAMGLASS® W+F and FOAMGLAS® T4+ (if considering only the Guarded Hot Plate Apparatus EP500 measurements).

Table 2: Summary of the test results

Product name	Source	Instrument	Density [kg/m³]	Temperature [°C]	Thermal conductivity [W/m.K]
FOAMGLAS® W+F	Manufacturer	-	100	10	0.0380
FOAMGLAS® T3+	Manufacturer	-	100	10	0.0360
FOAMGLAS® T4+	Manufacturer	-	115	10	0.0410
FOAMGLAS® S3	Manufacturer	-	130	10	0.0450
FOAMGLAS® F	Manufacturer	-	165	10	0.0500
Glapor®	Manufacturer	-	125	10	0.0540
FOAMGLAS® W+F	Current study	Hot Plate	94.7	10	0.0390
FOAMGLAS® W+F	Current study	Hot Plate	94.7	25	0.0462
FOAMGLAS® W+F	Current study	Hot Plate	94.7	40	0.0560
FOAMGLAS® T4+	Current study	Hot Plate	112.1	10	0.0481
FOAMGLAS® T4+	Current study	Hot Plate	112.1	25	0.0550
FOAMGLAS® T4+	Current study	Hot Plate	112.1	40	0.0665
FOAMGLAS® S3	Current study	Hot Plate	125	15	0.0530
FOAMGLAS® S3	Current study	Hot Plate	125	25	0.0597
FOAMGLAS® S3	Current study	Hot Plate	125	30	0.0646
FOAMGLAS® F	Current study	Hot Plate	175.7	10	0.0608
FOAMGLAS® F	Current study	Hot Plate	175.7	24	0.0702
FOAMGLAS® F	Current study	Hot Plate	175.7	35	0.0810
Glapor®	Current study	Hot Plate	133.5	10	0.0605
Glapor®	Current study	Hot Plate	133.5	25	0.0666
Glapor®	Current study	Hot Plate	133.5	40	0.0791
CTB	Current study	Hot Plate	132.8	10	0.0483
CTB	Current study	Hot Plate	132.8	25	0.0532
CTB	Current study	Hot Plate	132.8	40	0.0600
CTB	Current study	Hot box	132.8	28.8	0.0653

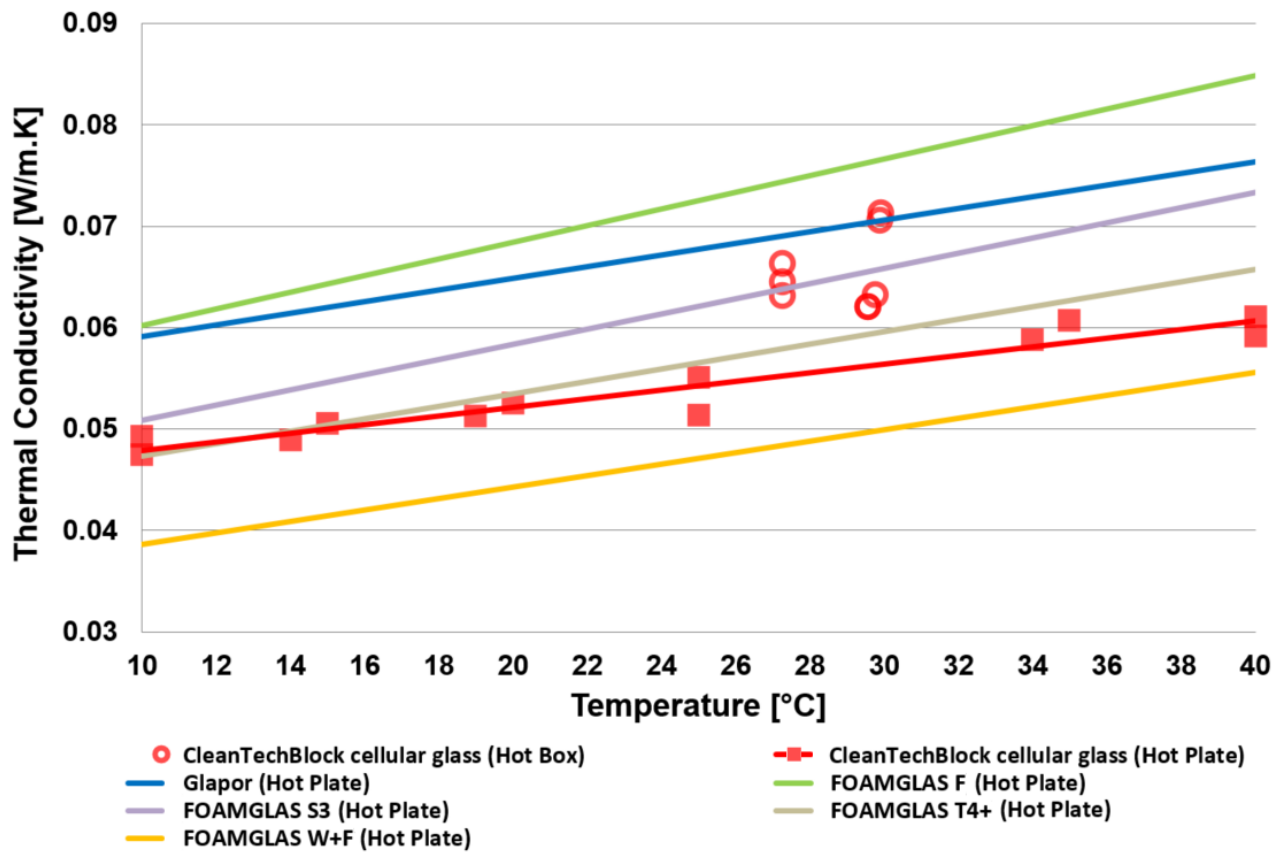


Figure 16: Thermal conductivity measurements (Guarded Hot Plate Apparatus EP500 and Guarded Hot Box setup) of the different study cases as function of temperature

One can see in *Figure* and *Figure 18* the thermal conductivity of the cellular glass study cases in comparison to other common building materials.

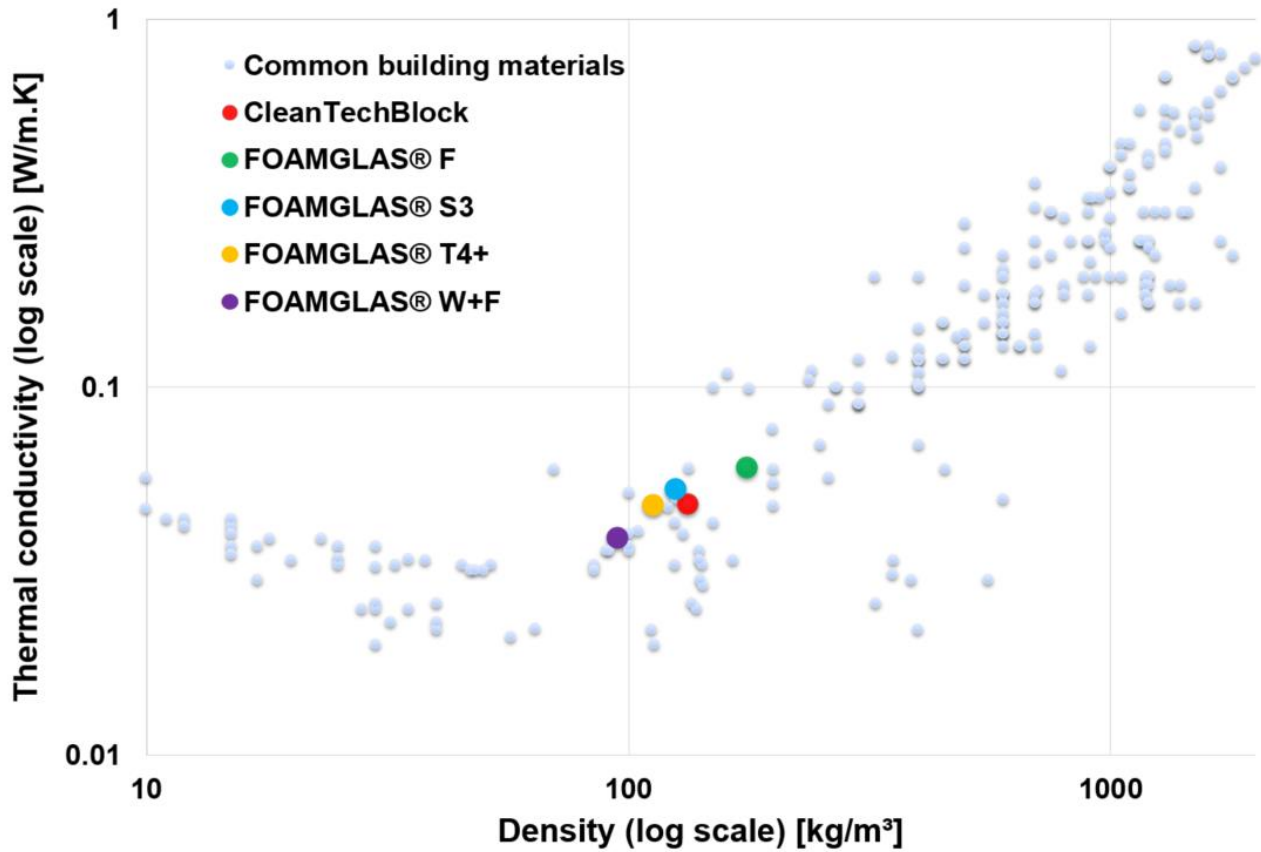


Figure 17: Thermal conductivity of common building materials and study cases cellular glass materials as function of density (at ambient temperature: 20 °C) [5]**Fejl! Henvisningskilde ikke fundet.**

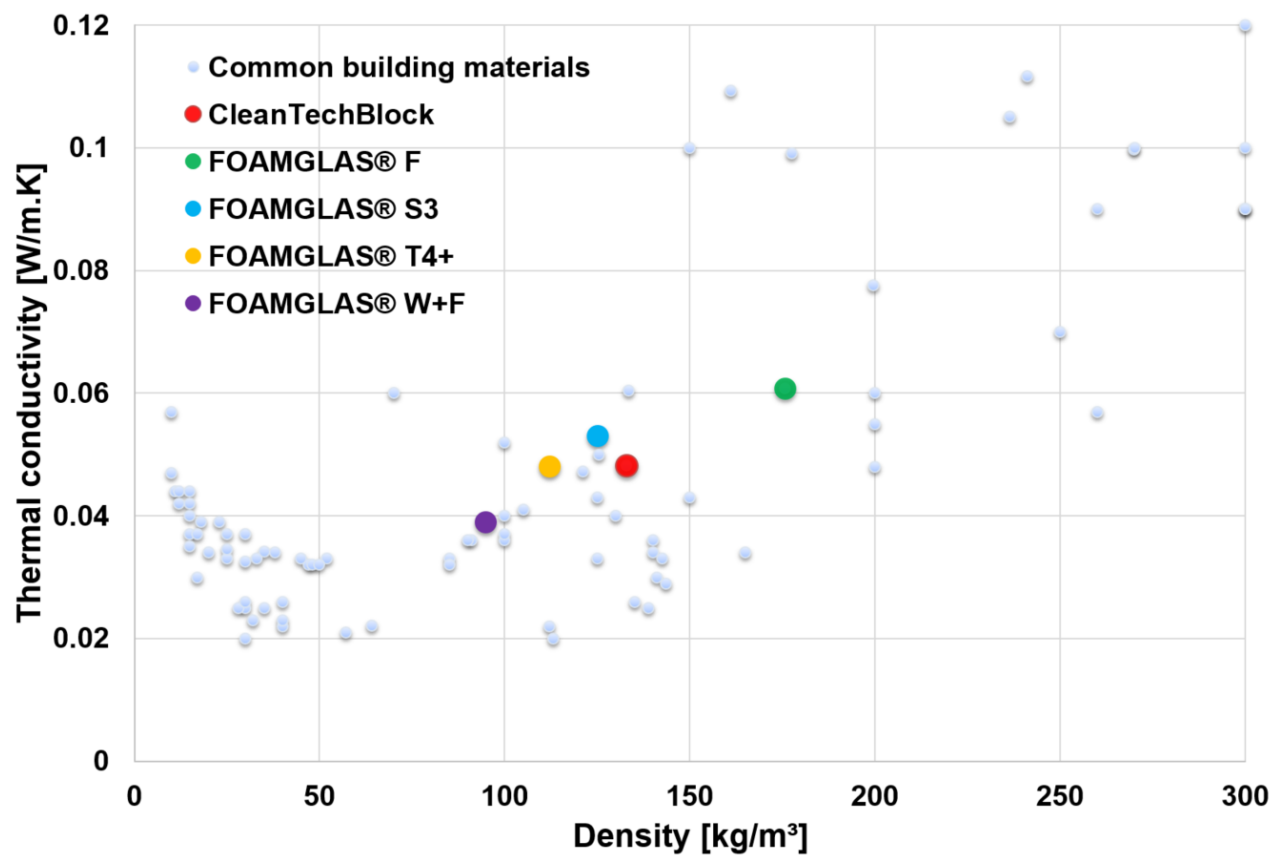


Figure 18: Thermal conductivity of common building materials and study cases cellular glass materials as function of density (at ambient temperature: 20 °C) [5] **Fejl! Henvisningskilde ikke fundet.**

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