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# Possibilities of development of advanced ceramic blocks for external masonry structures of low energy and passive constructions

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## ABSTRACT

Problems of global warming are nowadays still very actual and also the question of reduction of energy intensity of building at heating and cooling is closely related to them. Generally there are two basic ways for improvement of thermal insulating properties of envelope structures of buildings. It is either increase of envelop structure thickness either reduction of walling equivalent value of thermal conductivity. The paper deals with options of development of ceramic masonry blocks with very low equivalent value of thermal conductivity. They are mainly new types of ceramic blocks filled with insulating materials either on the orthodox base either on the base of secondary raw materials and industrial waste.

**Keywords.** Masonry ceramic blocks, thermal insulation materials, thermal conductivity alternative insulation materials, technical hemp, waste textile.

## INTRODUCTION

Continuous incensement of requirements in area of human development and quality of building constructions is possible to see in area of energy efficiency requirements of buildings (from point of view or heating and cooling too) and in area of energy efficiency of production of building materials and building of constructions. There is an effort to product building materials and components for envelope building structures with high thermal insulating properties as well decreasement of energy efficiency and $CO_2$ emission during of production process.

From point of view of $CO_2$ emission there are requirements described in UN Framework Convention on Climate Change/UNFCCC, Rio de Janeiro 1992 and following Kyoto Protocol, which was signed in year 1997.

Nowadays is signed a new Kyoto Protokol II, which will be valid till year 2020. Kyoto Protocol is related to six controlled greenhouse gases emission. Controlled is $CO_2$ gas equivalent production in each country which ratified the Protocol. Kyoto protocol enable to fulfill part of requirement with utilization of so-called flexibility mechanisms. These mechanisms should enable to provide reduction of emissions on the area of foreign country or buy up from other country right to exhalate greenhouse gasses. There are three types of flexibility mechanisms:

- Emission Trading, „ET“;
- Joint Implementation, „JI“;
- Clean Development Mechanism, „CDM“.

From point of above mentioned mechanisms is very important during building materials and components production utilization of secondary and easy renewable row materials. Waste materials enter to production process as secondary row materials with low or even zero energetic balance and with zero $CO_2$ emission. In case of waste destined to burning after the end of their life cycle, is recyclation process positive from point of view of $CO_2$ emissions (decreasement of $CO_2$ emissions thanks to recyclation process). Easy renewable row materials on natural base from agriculture enter to production chain with negative $CO_2$ emission balance. Thanks to this consequence the total $CO_2$ emission of final material or product decrease. With good production technology can be the final $CO_2$ emission balance of production process negative. This fact can be very valuable from point of view of “CDM” and can be very positive in some region, where is material produced (from point of “ET”).

## INCREASING OF THE THERMAL INSULATING PROPERTIES OF CERAMIC BLOCKS

In the field of ceramic fittings there are generally four ways to improve their thermal properties:

- Increasing width of the fittings, ie increasing of the thickness of walls;
- Reduction of thermal conductivity of ceramic body;
- Increasing of the number of cavities and design of optimal geometry blocks;
- Integrated use of thermal insulation with low thermal conductivity.

Increasing of width of the fittings for building cladding in the long run leads to an increase in the thickness of the building envelope. This trend is unsustainable, also brings with it a number of negatives in the form of increased weight of the masonry bricks (at a standard scale compositional elements), problems in filling holes, etc. Currently masonry width fittings for building envelopes in low-energy and passive standard reached the value of 500 mm, which can be regarded as the limit value. Further increasing the thickness of the masonry is very difficult and also largely ineffective.

Reducing of the thermal conductivity of the ceramic body is strongly tied to the quality of the feedstock and the possibility of lightening. Reducing density of the ceramic body leads to a decrease in thermal conductivity. Lightening of ceramic body but outside reducing the thermal conductivity leads to a reduction in mechanical properties of the body. A high proportion of lightener problematic from the technological point of view, it is mainly to increase the sensitivity of the drying and burning out lightener problem when firing.

Lightening of ceramic shaped air cavities was previously regarded as the most effective way of increasing of their thermal specification. Lightening efficiency depends both on the ratio of the volume of air voids to the volume of ceramic skeleton, and then shaped cavities, their arrangement, the thickness of the inner and outer wall tiles and the size of the cavities.

Quite progressive path is the integration of thermally insulating material into the cavity ceramic fittings. This way it is possible to significantly reduce the thermal conductivity of the ceramic shaped cavities, and completely eliminate the convection inside fittings. To fill cavities ceramic fittings must always be used the insulation materials with the lowest thermal conductivity, which must always be lower than the thermal conductivity of air fittings cavities to be filled with the insulator. Thermal insulator must always be easily applied to cavities fittings.

## THERMAL INSULATING MATERIAL BASED ON WASTE PUR AND EPS

This paper describes the possibilities of using waste PUR and EPS, as integrated insulation into the ceramic fittings for external masonry walls. For research purposes, the samples were used of PUR foam waste of fraction 3-6 mm, which arises crushing residues originating from formatting boards and molded polyurethane foam products. Furthermore, it was a waste of EPS fraction 1-4 mm, which is produced in the manufacture of molds for the production of concrete goods.

The feedstock was carried out by determining the bulk density of EN 1097-3. Bulk density of polyurethane granules was determined to 39.2 $kg.m^{-3}$ and bulk density of polystyrene EPS is 13.5 $kg.m^{-3}$.

Three trial mixes were suggested for the testing, which were placed in a heated mold (dimensions 40x40x160 mm and 300x300x50 mm). These test samples were loaded 8 kg weight.

The first batch was mixed in the ratio of 50:50, polyurethane granulate: EPS together with water, then was cured in an oven at 140 °C for 30 minutes (temperature of the form 71.1 °C), then the temperature was increased to 150 °C for next 10 minutes (form temperature 77 °C).

The second batch was mixed in the ratio of 50:50, polyurethane granulate: EPS together with water and glue was further cured in an oven at 130 °C for 30 minutes (form temperature 71 °C).

The third batch was mixed in the ratio of 50:50, polyurethane granulate: EPS together with water and glue was further cured in an oven at 140 °C for 30 minutes (form temperature 71.1 °C).

**Figure 1. Photos of insulating samples based on PUR waste and waste of EPS granulate**

After demoulding these batches can be stated that the specimens that were bonded with the mixture of glue and water were fragile, but hold the shape. Conversely specimens of the first batch, which were prepared with only water, disintegrated.

These prepared batch were subjected to determine values of the thermal conductivity in the steady state according to EN 12667, ISO 8301 (at an average temperature of +10 ° C and a temperature gradient of 10K) in the mixture 1, which did not hold shape, the granulate was thrown into a wooden frame.Physical properties of test samples were determined:

- thickness according to EN 823,
- linear dimensions according to EN 12085,
- density according to EN 1602.

**Table 1. Overview of measured physical and thermal technical properties of test samples**

| Composition | $m$ | $l$ | $b$ | $h$ | $\rho_v$ | $\lambda_{10,dry}$ |
|---|---|---|---|---|---|---|
| | [g] | [mm] | [mm] | [mm] | [kg.m$^{-3}$] | [W.m$^{-1}$.K$^{-1}$] |
| **1** | **11,87** | 160,16 | 40,01 | 38,18 | **48,5** | **0,0332** |
| **2** | **15,27** | 161,51 | 40,1 | 32,65 | **72,2** | **0,0387** |
| **3** | **13,06** | 157,54 | 40,65 | 32,75 | **62,3** | **0,0391** |

note: $m$ – weight; $l, b, h$ – dimensions; $\rho_v$ – bulk density, $\lambda_{10,dry}$ – thermal conductivity.

## MODEL OF CERAMICS BLOCKS WITH INTEGRATED THERMAL INSULATION

There was model of ceramic fittings for masonry, was designed during research work for thickness 500 mm. Fittings were lightened by large cavities with a thickness of 40, 50 and 90 mm (total 7 series).

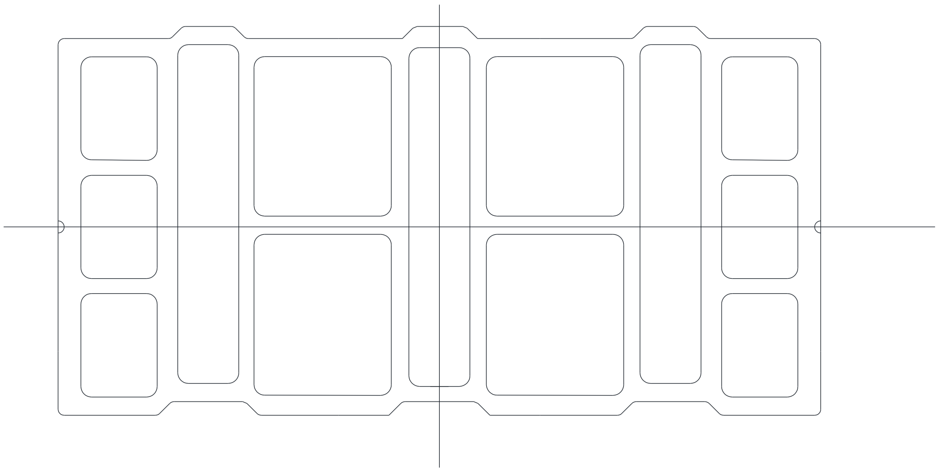

**Figure 2. Scheme of geometric layout of ceramic block with integrated thermal insulation**

Masonry bricks were filled with insulating material from waste of PUR and EPS (mixtures 1, 2 and 3). The insulater was fixed in the crosspiece in the case of mixture n. 2 and n. 3. There are assumed additional fittings for filling in rows directly on the site in application of insulator according to mixture 1.

Thermal insulating properties of the wall from developed masonry components were set by calculation in accordance with EN 1745 using finite element method. The analysis model of the brickwork was set upon the geometric layout of the blocks (Fig. 1). The masonry model was loaded during calculation with edge conditions typical for Central Europe (external temperature: -15 °C; internal temperature +21 °C). Thermal conductivity values of insulants stated in the table 1 were selected for the calculation in respect of material properties and further thermal conductivity values of ceramic body $\lambda_{10,\ dry}$: 0.275; 0.300; 0.325 and 0.350 $W.m^{-1}.K^{-1}$. These values were set as reference ones upon performed research in the field of typical thermal conductivity values of thermal insulating shaped pieces from EU leading producers. The calculations were carried out for dried blocks and calculated values are stated in the table 2 to 4 bellow.

**Table 2. Calculated values of thermal properties of experimental masonry blocks filled with insulation – composition n. 1 ($\lambda_{insulation}$ = 0.0332 W.m$^{-1}$.K$^{-1}$)**

| Properties | $\lambda_{clinker}$ [W.m$^{-1}$.K$^{-1}$] | | | |
|---|---|---|---|---|
| | 0.275 | 0.300 | 0.325 | 0.350 |
| ***U*** [W.m$^{-2}$.K$^{-1}$] | 0.1431 | 0.1497 | 0.1561 | 0.1625 |
| ***R*** [m$^{2}$.K.W$^{-1}$] | 6.8231 | 6.5150 | 6.2411 | 5.9888 |

**Table 3. Calculated values of thermal properties of experimental masonry blocks filled with insulation – composition n. 2 ($\lambda_{insulation}$ = 0.0387 W.m$^{-1}$.K$^{-1}$)**

| Properties | $\lambda_{clinker}$ [W.m$^{-1}$.K$^{-1}$] | | | |
|---|---|---|---|---|
| | 0.275 | 0.300 | 0.325 | 0.350 |
| ***U*** [W.m$^{-2}$.K$^{-1}$] | 0.1540 | 0.1606 | 0.1672 | 0.1737 |
| ***R*** [m$^{2}$.K.W$^{-1}$] | 6.3285 | 6.0617 | 5.8159 | 5.5921 |

**Table 4. Calculated values of thermal properties of experimental masonry blocks filled with insulation – composition n. 3 ($\lambda_{insulation}$ = 0.0391 W.m$^{-1}$.K$^{-1}$)**

| Properties | $\lambda_{clinker}$ [W.m$^{-1}$.K$^{-1}$] | | | |
|---|---|---|---|---|
| | 0.275 | 0.300 | 0.325 | 0.350 |
| ***U*** [W.m$^{-2}$.K$^{-1}$] | 0.1548 | 0.1614 | 0.168 | 0.1745 |
| ***R*** [m$^{2}$.K.W$^{-1}$] | 6.2949 | 6.0308 | 5.7874 | 5.5657 |

Note: *U*– Thermal transmission coefficient, *R*– thermal resistance, $\lambda_{clinker}$– thermal conductivity of ceramic clinker.

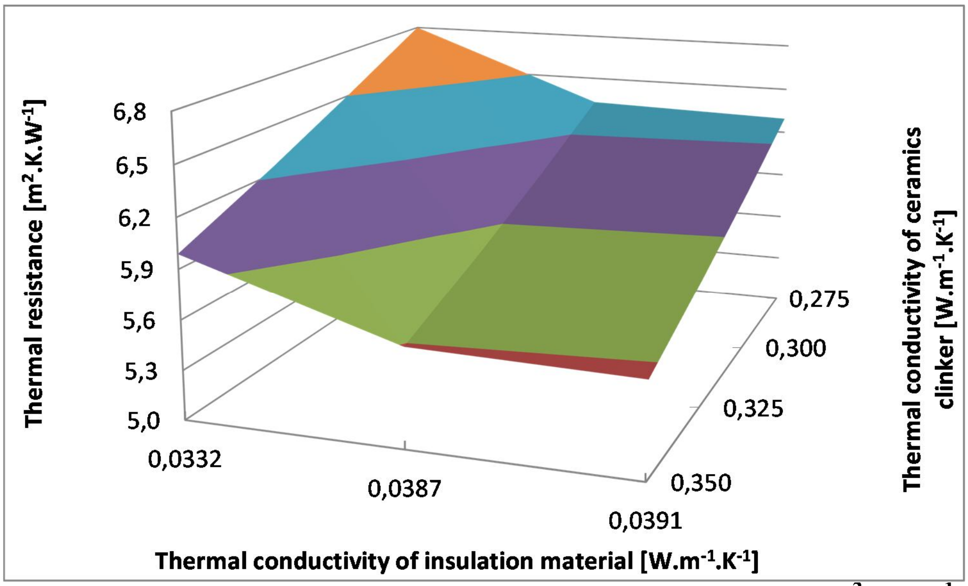


**Figure 3. Thermal resistance dependence of masonry blocks *R* [m$^2$.K.W$^{-1}$] on thermal conductivity of ceramic body for different variants of insulants**

It is clear from obtained results that the developed ceramic blocks show very good thermal insulating properties. From the calculated values and figure no. 2 it is clear that differences between insulating properties of masonry structures from insulating blocks filled with various types of insulants are significant. Total difference in all cases is around 8 % (at similar value of thermal conductivity of ceramics body). In this case the ceramic body thermal conductivity shows itself as a key value too where total difference of thermal insulating properties for ceramic body thermal conductivity limits exceeds 12 %.

## CONCLUSION

At designing of ceramic blocks with integrated thermal insulating filling it was found that insulating materials made from PUR and EPS waste can be used as filling of masonry block big size cavities.

Generally it was found that ceramic blocks with integrated thermal insulating layer show with 500 mm thickness the thermal resistance value (in dried condition) within 5.57 – 6.82 m$^2$.K.W$^{-1}$, which matches with value of thermal transmission coefficient within 0,1431 – 0,1745 W.m$^{-2}$.K$^{-1}$. Resultant values of thermal insulating values of masonry construction made from these blocks in status of practical moisture will develop from selected technology of walling. However it can be expected that during walling on mortar for thin joints the final thermal resistance of final brickwork at practical moisture 1% will not be lower for approx. 6% than calculated values for particular blocks.

Alternative insulating materials show comparable thermal insulating properties as orthodox ones.

Utilization of PUR and EPS waste save energy and $CO_2$ (greenhouse gases) emissions in comparing with utilization of orthodox thermal insulating materials. So, development of masonry components with inbuilt layer of thermal insulation based on waste PUR and EPS is valuable from environmental point of view.

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