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NZEBs built of elements based on styrofoam re-granulate

M Wesołowska[1], P Szczepaniak[1], J Gajewski[2]

[1] UTP University of Science and Technology in Bydgoszcz, Department of Building Engineering and Building Physics, Al. prof. S.Kaliskiego 7, 85-796 Bydgoszcz, Poland

[2] UTP University of Science and Technology in Bydgoszcz, Department of Building Construction, Al. prof. S.Kaliskiego 7, 85-796 Bydgoszcz, Poland

Maria.Wesolowska@ utp.edu.pl

Abstract. In the article there was introduced an idea of NZEB constructed from large size wall elements mounted with dry connection and horizontal joints filled with polyurethane mortar. The proposed element was 50 cm thick with set of layers made of styro-concrete with EPS re-granulate and EPS-032 separation layers. The result was a solution with high thermal isolation and traditional division for construction and isolation zones. Additional elements of the system are layered lintels and intermediate moldings with increased pressing strength. The material solutions of the system elements are the effect of combined construction and thermal analyses.

1. Introduction
Expanded polystyrene is currently the most often used material in thermal insulation of construction. During modernization of thermal insulation, repairs, and demolition work a lot of this material is amounted. Ono of possibilities for its use is to recycle it as ecostyrene[5].In this form it can be applied as filling for construction, insulation for construction partitions, elastic bedding for roads and sport arenas, and as insulation for thermal exchangers and swimming-pools.Ecostyrene is also used as water-protective insulation[3](styrozolcreated during solution of polystyrene with solvent, and next enriched with plasticizers and fillers for water-resistant features). There is also re-granulate on the market, sized from about 2 to 10 mm[6] used as bulk material or concrete filler[4]. The resulted concrete is weaker[1], but with enhanced thermal properties.It opens possibility of using this material for production of elements for NZEB(nearly zero-energy building).According to the Directive 2010/31/EU[2] 'nearly zero-energy building' means a building that has a very high energy performance (…). The nearly zero or very low amount of energy required, should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

2. Solution description
The goal of this project was creation of an alternative system of low-budged passive building using production and execution work wastes of expanded polystyrene (EPS). Multi-layer wall elements were designed with vertical tongue-and-groove joints made from two materials:

- 50 mm thick boards from styro-concrete of900density classwith 30% addition of organic filler of the EPS re-granulate, from crushed wastes,

- 50 and 200mm thick boards from the EPS 70-031 graphite styrofoam.

The layers are bound with polyurethane mono-component polyurethane glue and additionally screwed with steel tie-rods of 6 mm in diameter, equipped with polyamide collar nuts(Figure 1). The tie-rods ensure the proper pressure during the glue settingand additional reinforcement of the element during construction. After building-in the protruding part of a tie-rod is cut out and masked with a styrofoam plug.

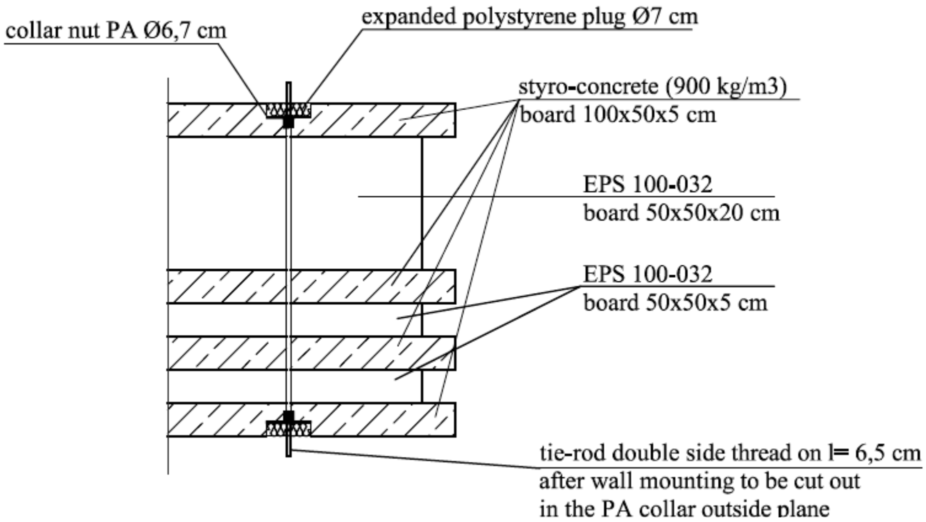

Figure 1. Tie-rod solution in a multi-layer wall element.

The set includes: base wall elements sized 105x50x50cm (Figure2), supplement half elements (longitudinal 105x25x50 cm,and transverse 55x50x50cm) and quarter base elements reinforced with ferroconcrete plate under the lintel support.In the elements there was preserved the traditional division of functions:

- construction layer 25cm thick,
- thermal insulation layer 20cm thick,
- styro-concrete of 5cm as a stabile base for thin-layered plate with a steel reinforcement net.

Figure 2. Ekoblok wall system elements.

The fixed measurements allow to erect walls with required translation of vertical contacts by using a half-element and without necessity of cutting:

- window sill level: 2 basic elements (2x50=100cm),

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- lintel level: 4 basic elements + quarter-element,
- ring beam level: 6 basic elements or 5 basic elements + quarter-element.

The proposed layer layout of a large-block element will allow to support the ceiling and building ring beam with necessary insulation minimizing influence of the thermal bridge in this node. Open joints created by vertical hole edges will be filled with styrofoam inserts on building site which minimizes heat loss in area of jambs. The system is prepared for using modular hole widths: 90 cm, 120 cm, 220 cm, and 270 cm. This solution allows using monolithic and prefabricated door lintels (Figure 3).Basic solution of building setting predicts linear foundation with both sides of perimetric insulation.

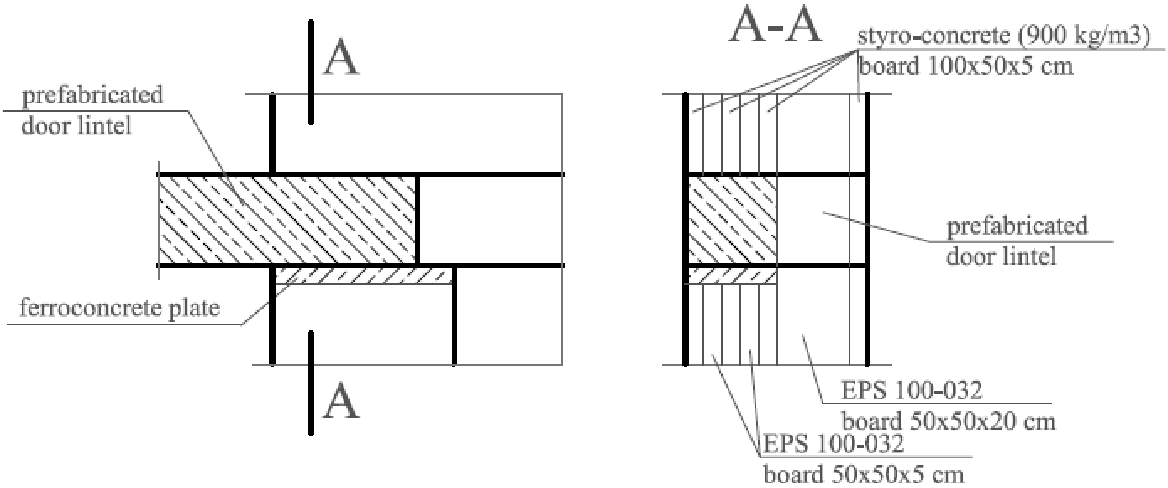

Figure 3. Ekoblok system node of door lintel support.

3. Construction designs analysis

The system is designated for erecting of passive buildings. The basic requirements for this type of buildings are listed in Table 1. The heat permeation coefficient of a wall element is U=0.100W/(m^2·K). The division of a construction layer in the element ensures continuity of thermal insulation in most nodes of walls. However, the construction solution used (steel tie-rods, joint, tying of wall with layer elements in the corner, door lintel support) interfere with the specific thermo-insulating layer.

Table 1. Minimal energetic requirements for buildings

Energy standard	**NZEB**	**Passive[7]**
	thermal transmittance U [W/m^2·K]	
wall (T_i>16 ºC)	0.20	0.10
roof	0.15	0.10
slab-on-ground	0.30	0.12
	linear thermal transmittance Ψ [W/m·K]	
all thermal bridges	no requirements	recommended value: 0.01 maximum value: 0.05
	energy factors	
primary energy factor [kWh/(m^2·rok)]	70	70
heating energy factor [kWh/(m^2·rok)]	-	15
T_i - inertia temperature		

3.1. Analysis of steel tie-rod influence

In connection with reaching the assumed limit value of a heat transfer coefficient for the element it was necessary to propose a tie-rod design which minimized its influence during the wall functioning. In order to achieve this goal there was assumed a piercing the wall element with a steel connecting rod in half of the wall element volume (Figure 4). The spot heat transfer coefficient $\chi$was calculated with the formula:

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \cdot A_i - \sum_{j=1}^{N_j} \Psi_j \cdot l_j \quad (1)$$

where:

L_{3D}–heat coupling coefficient from calculation of 3-D component, separating the two discussed environments,

U_j–heat transfer coefficient of 1-D j component, separating the two discussed environments,

l_j–length along which the value of U_j is applied.

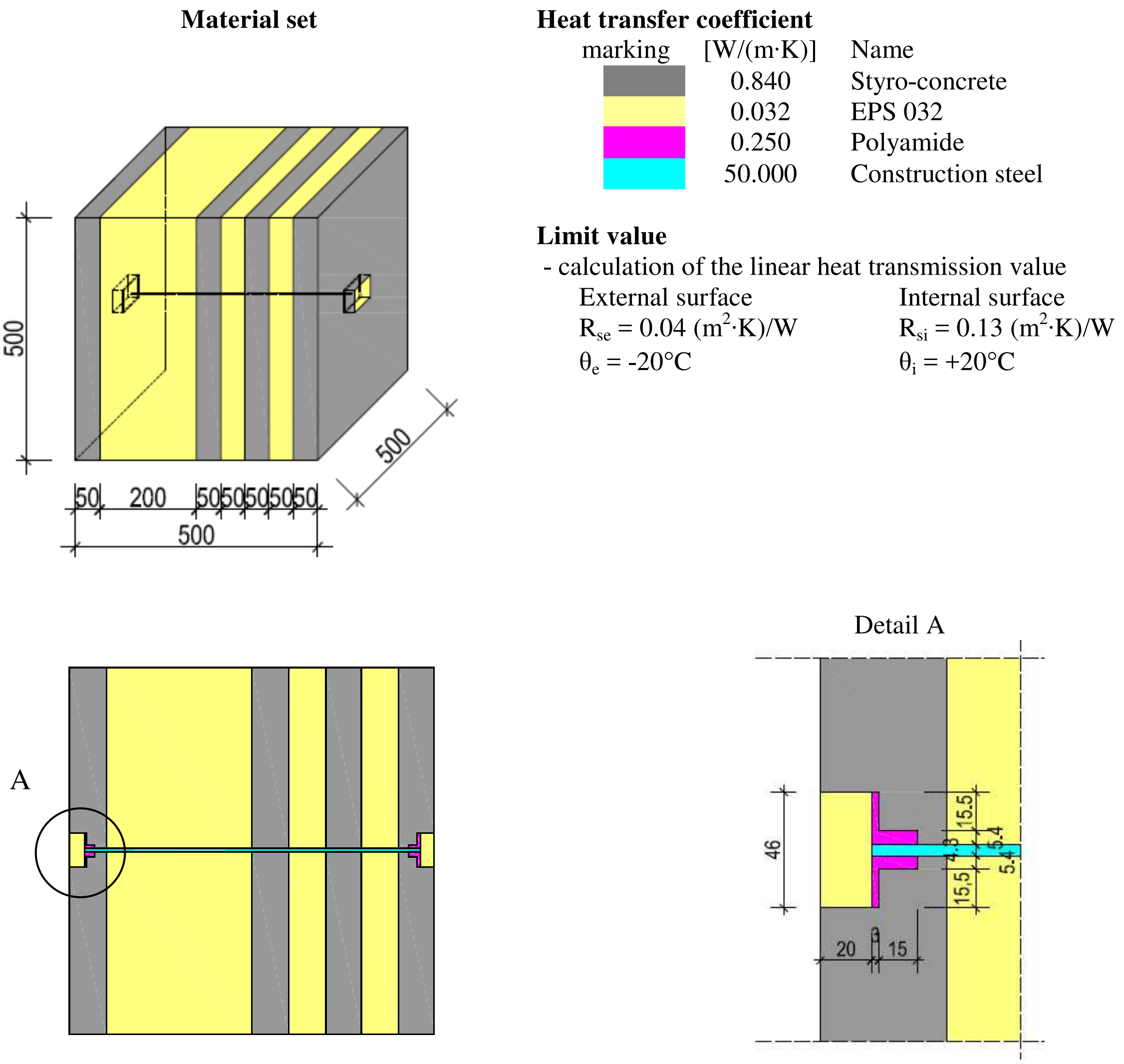

Figure 4. Calculation modelfor definition of mechanic connector influence.

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In the discussed case there are no values of linear heat conductivity coefficient Ψ, so the value of χis:

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \cdot A_i = 0.028 - 0.100 \cdot 0.25 = 0.002\ W/K \tag{2}$$

The coefficient $U_c$for the basic element with tie-rods amounts to 0.104 W/(m^2·K).

3.2. Selection of material set for joints

The joint passing through all layers of wall element is in contact with internal and external environment which interfere the continuity of the isolated thermal insulation layer.On the horizontal joint of wall elements there is created a linear bridge transferring into spatial bridge in the corner. In this place the geometric bridge and mutual penetration of horizontal and vertical joints overlay (Figure 6).

In order to limit the influence of the spatial thermal bridge, thin joints were proposed (3 mm). Two material solutions were discussed:

- Mineral mortar for thin joints (λ = 0.900 W/(m·K)),
- Polyurethaneglue (λ = 0.036 W/(m·K)).

In a 2D analysis of joining wall elements with a supporting joint, with assumed thickness of 3 mm, heat conductivity of mortar has secondary significance. The joint does not influence the heat transfer coefficient value U for the wall. The influence of mortar is visible in the2Dand 3D node model of the corner (Figure 5, Table 2).

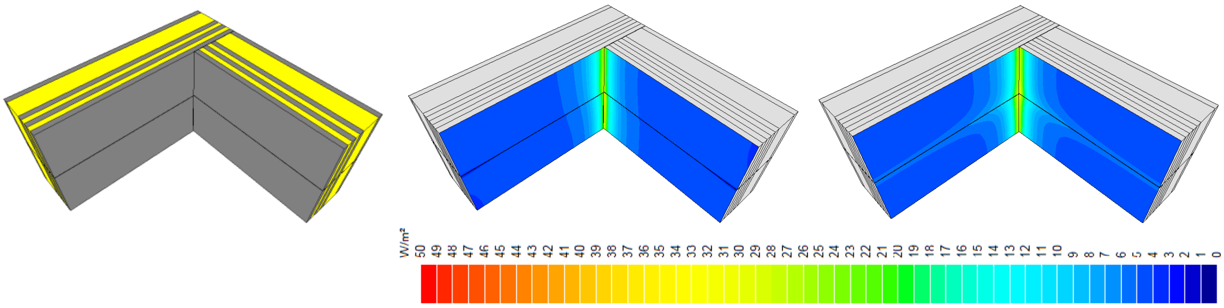

Figure 5. Mortar influence on heat flux distribution in the joint.

Table 2. Evaluation of heat quality for connecting node of external walls

	Mineral mortar for thin joints	**Polyurethane glue**
$\Psi_{vertical}$ [W/(m·K)]	0.056	0.050
$\Psi_{horizontal}$ [W/(m·K)]	0.014	0.000
χ [W/K]	0.040	0.028

In both material solutions of the mortar, the obtained value of the linear heat transfer coefficient for the analyzed node is below the acceptable value (Table 2). However, the node geometry and the path of materials in the node do not allow to reach the recommended value. The picture of the stream field in a3D model (Figure 5) indicates that it is more proper to use polyurethane mortar both in the horizontal and vertical joints.

3.3. Solution of door lintel supporting on wall

The places of door lintel support on walls are zones especially threatened with damage. The essential issue is to define the minimum depth of support ensuring safe transfer of load from the door lintel to walls. To achieve this goal there was performed a detailed material strength analysis. A FEM three-dimensional model of the door lintel was prepared using volume elements with a linear shape function.

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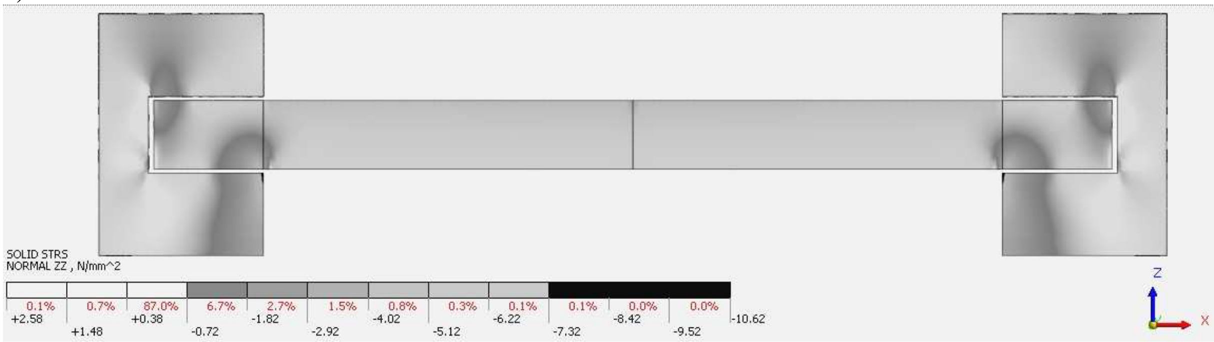

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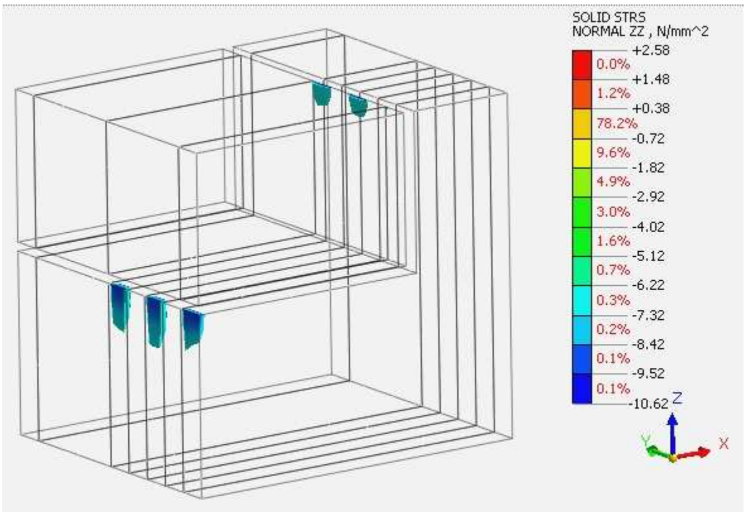

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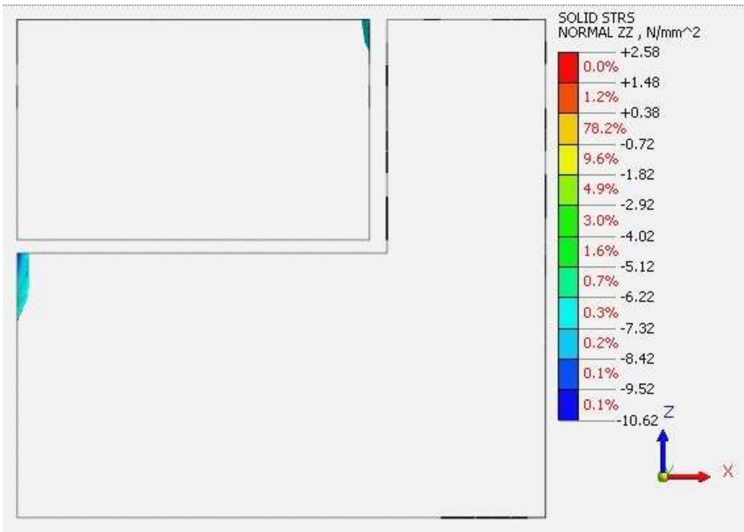

Figure 6. Results of material strength calculations for a 270cm door lintel, with 40 cm support a) entire lintel (strain$\sigma_{ZZ,max}$= -10.62 MPa), b) axonometric projection (σ_{ZZ} from -7 to -10.62 MPa), c) side view (σ_{ZZ} od -7 do -10.62 MPa).

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In analyses there was assumed a linear and resilient material model for styrofoam and concrete. In thethe FEM model MES the following values of Young's modulus were assumed as: 30GPafor concrete, 15 GPafor styro-concrete, 1.5MPa for styrofoam.
Based on material strength analysis the minimum depths of door lintel support were defined:

- 40 cm for the case of 270 cm holedoor lintel,
- 30 cm for the case of 220 cm holedoor lintel,
- 20 cm for the case of 120 cm holedoor lintel.

It was also defined that in the support edge zone there is a strain concentration which can lead to a creation of scratches in styro-concrete boards. Thus the half-element was modified by insertion of a horizontal ferroconcrete plate in construction zone.
The created material set introduces a heat flux concentration in a hole corner area (Figure 7). This concentration results in lowering of temperature on the surface, but it is not threatened by mildew development.

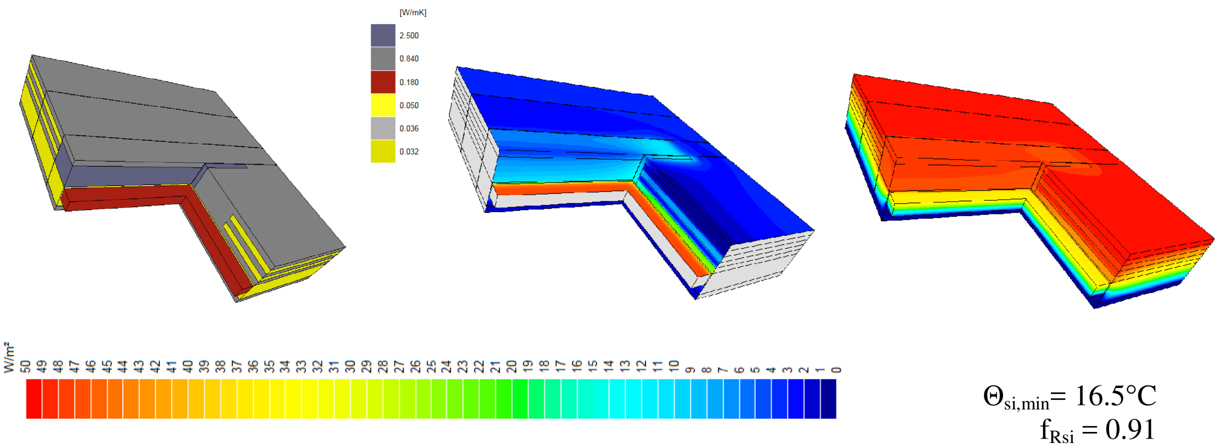

Figure 7. Distribution of heat flux in the door lintel construction node

4. Summary

The heat calculations performed for the element indicate that the thermal bridges generated by spot anchoring do not introduce correction whichresults in exceeding the limit values of heat transfer coefficient U. The translation of boards forms a tongue and groove joint which allows dry connection and air tightness of the wall.The thin-layered joint does not affect the heat transfer coefficient U for the wall. The material solutions of the mortar used for connection of wall elements are decided by spatial bridges. The bearing zone distinguished in the element has a layer layout. The introduction of necessary construction solutions,though they are closing within its borders has its consequences in heat transport.This is hardly visible in a typical 2D analysis. The flux disturbances are noticeable in a spatial temperature field.

The sizes of elements and erection technology gives possibility for execution of a passive building in shorter time than for traditional solutions.It also utilizes industrial wastes.However, because of its construction and shape it has not equivalents in standards. Its implementing into building practice is conditioned by detailed regulations. In this area the binding regulation is the Regulation of the European Parliament and of the Council (EU) No 305/2011 of 9March 2011 laying down harmonized conditions for the marketing of construction productsand repealing the Council Directive 89/106/EEC.

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