Komisja Architektury i Urbanistyki
Polska Akademia Nauk Wrocław, Oddział we Wrocławiu
Międzynarodowe Warsztaty Naukowe „Innowacyjne Systemy Konstrukcyjne w Architekturze”
(ISSA2021) 5-6 listopada 2021 r., Wrocław, Polska

PAPER AS MATERIAL IN BUILDING PARTITIONS – THERMAL PROPERTIES

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Słowa kluczowe: *thermal properties, paper-based materials, thermal insulation, paper partitions, corrugated cardboard*

ABSTRAKT

When using paper-based products in architecture, an important issue is to meet the requirements of adequate thermal insulation of a building envelope. The basic thermal properties of building materials are thermal conductivity (λ) and specific heat (c_p). Knowing the thermal conductivity coefficient allows for the calculation of the U-value parameter of the building envelope, which directly affects the energy consumption of the building. The specific heat and density of a material determine the dynamics of heat flow through this material, which affects the thermal stability of the building envelope.

The thermal parameters of the paper-based material can be found in the international standards (EN ISO 10456: 2009 [1] and EN ISO 6946: 1999) [2] and in the thermal simulation software databases (eg WUFI). Most often, the thermal parameters of paper-based materials are a combination of thermal insulation of paper as a solid material and the air contained between this material (eg corrugated cardboard or paper honeycomb boards). The thermal insulation of non-ventilated air voids can be found in EN ISO 6946: 2017-10 [3] and EN ISO 10077-1: 2017 [4] and in the WUFI program database. Heat flow in paper-based materials with air voids is the result of conduction, convection and radiation of heat in these materials (complex heat flow model) [5]. The best way to determine the thermal conductivity of such materials is to measure this parameter using a plate apparatus (eg FOX 314). In Table 1 presents the thermal parameters of paper-based materials and several typical building materials based on the review of the current literature on the subject

(scientific articles [6-10], international standards [1-4] and databases of computer programs [11,12]).

Tab.1 The thermal parameters of paper-based materials and several typical building materials based on scientific articles [6-10], international standards [1-4] and databases of computer programs [11-12].

1	2	3	4	5	6	7	8	9	10	11
No.	Material	Science article			International standards			Software database		
		Thermal conduct.	Specific heat	Density	Thermal conduct.	Specific heat	Density	Thermal conduct.	Specific heat	Density
[-]	[-]	λ [W·m^{-1}·K^{-1}]	c_p [J·kg^{-1}·K^{-1}]	ρ [kg·m^{-3}]	λ [W·m^{-1}·K^{-1}]	c_p [J·kg^{-1}·K^{-1}]	ρ [kg·m^{-3}]	λ [W·m^{-1}·K^{-1}]	c_p [J·kg^{-1}·K^{-1}]	ρ [kg·m^{-3}]
1	Reinforced concrete	-	-	-	2,500	1000	2400	-	-	-
2	Solid brick	-	-	-	0,770	880	1800	-	-	-
3	**Paper**	**-**	**-**	**-**	**0,250**	**1460**	**1000**	**0,420**	**1500**	**120**
4	**Cardboard**	**-**	**-**	**-**	**0,140**	**1460**	**900**	**0,072**	**1400**	**480**
6	Aerated concrete	-	-	-	0,140	840	400	-	-	-
7	Wood	-	-	-	0,120	1600	450	-	-	-
8	**Honeycomb panel h=68mm**	**0,117**	**-**	**24,5**	-	-	-	-	-	-
9	**Honeycomb panel h=29mm**	**0,090**	**-**	**37,4**	-	-	-	-	-	-
10	**Honeycomb panel h=17mm**	**0,077**	**-**	**38,7**	-	-	-	-	-	-
11	**Honeycomb panel h=12,5mm**	**0,071**	**-**	**48,3**	-	-	-	-	-	-
12	**Corrugated cardboard E-flute**	**0,055**	**-**	**276,0**	-	-	-	-	-	-
13	**Corrugated cardboard C-flute**	**0,049**	**-**	**132,0**	-	-	-	-	-	-
14	**Corrugated cardboard BC-flute**	**0,050**	**-**	**100,0**	-	-	-	-	-	-
15	**Corrugated cardboard A-flute**	**0,047**	**-**	**80,0**	-	-	-	-	-	-
16	**Cellulose granulate**	**-**	**-**	**-**	**0,039**	**1600**	**32**	**0,039**	**1381**	**48**
17	EPS (expanded polystyrene)	-	-	-	0,032	1450	15	-	-	-
18	Mineral wool	-	-	-	0,030	1030	100	-	-	-

The basic thermal parameter of building partitions, required by Polish law (WT 2019) [13], is the thermal transmittence coefficient $U_{c(max)}$. For an external wall, this parameter cannot exceed the value of 0.20 W / m^{2}K. The U_c factor is calculated from the formula (1) (based on ISO 6946: 2017) [3]:

$$U_c = \frac{1}{R_{si} + \sum_{i=1}^{n} \frac{d_i}{\lambda_i} + R_{se}} + \Delta U \left[\frac{W}{m^2 K}\right] \qquad (1)$$

U_c - is the corrected thermal transmittance [W/m^{2}K]
R_{si} - is the internal surface resistance (value 0,13 is assumed) [m^{2}K/W]
d_i - is the thickness of each material layer (i) in the component [m]
λ_i - is the design thermal conductivity of each material (i) [W/mK]
R_{se} - is the external surface resistance (value 0,04 is assumed) [m^{2}K/W]
ΔU - is the correction to thermal transmittance (value 0 is assumed) [W/m^{2}K]

Taking into account the above formula (1) and the thermal parameters contained in Table 1, it is possible to calculate the minimum thickness of homogeneous partitions consisting of one type of material, for which the current requirements for the thermal transmittance coefficient for the external wall are met (Table 2).

Tab.2 The minimum thickness of homogeneous partitions consisting of one type of material, meeting the current requirements for the thermal transmittance for the external wall.

1	2		3	4	5	6
No.	Material	Internal surface resistance	Thermal conduct. of material	External surface resistance	Corrected thermal transmittance	Thickness of material
		R_{se}	λ	R_{si}	U_c	d
[-]	[-]	[m^2K/W]	[$W \cdot m^{-1} \cdot K^{-1}$]	[m^2K/W]	[W/m^2K]	[cm]
1	Reinforced concrete	0,13	2,500	0,04	0,20	1 207,5
2	Solid brick		0,770			371,9
3	**Paper**		**0,250**			**120,8**
4	**Cardboard**		**0,140**			**67,6**
6	Aerated concrete		0,140			67,6
7	Wood		0,120			58,0
8	**Honeycomb panel h=68mm**		**0,117**			**56,5**
9	**Honeycomb panel h=29mm**		**0,090**			**43,5**
10	**Honeycomb panel h=17mm**		**0,077**			**37,2**
11	**Honeycomb panel h=12,5mm**		**0,071**			**34,3**
12	**Corrugated cardboard E-flute**		**0,055**			**26,6**
13	**Corrugated cardboard C-flute**		**0,049**			**23,7**
14	**Corrugated cardboard BC-flute**		**0,050**			**24,2**
15	**Corrugated cardboard A-flute**		**0,047**			**22,7**
16	**Cellulose granulate**		**0,039**			**18,8**
17	EPS (expanded polystyrene)		0,032			15,5
18	Mineral wool		0,030			14,5

By analyzing the literature review on thermal parameters of paper-based materials, it can be concluded that:

a) honeycomb panel has worse thermal conductivity values than corrugated cardboard,
b) paper materials have thermal parameters similar to materials commonly used in construction as thermal insulation,
c) with correspondingly greater thicknesses, paper materials can effectively replace mineral wool and polystyrene in terms of thermal protection of building partitions,

d) the most effective thermal insulation can be obtained with cellulose fibre and corrugated cardboard with smaller flute sizes,
e) it should be noted, that paper is particularly sensitive to moisture, therefore thermal properties of paper-based insulation decrees with the increase of air humidity,
f) there is lack of knowladge about dynamic thermal parameters such as heat specific capacity for each type of paper-based products (data only exists for solid materials),
g) there is lack of knowladge about thermal conductivity coefficient for both directions of heat flow in materials such as corrugated cardboard and honeycomb.

[1] EN ISO 10456:2007 Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values.

[2] EN ISO 6946:1999 Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods

[3] EN ISO 6946:2017-10 Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods

[4] EN ISO 10077-1: 2017 Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 1: General

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[11] WUFI PRO 6.5 database: www.wufi.de, access: 2021.10.22.

[12] Integrated Environmental Solutions (IES) database: www.iesve.com, access: 2021.10.22.

[13] Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 14 listopada 2017 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie. Dz.U. 2017 poz. 2285.