ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 4. 2006

Performance of Loose-Fill Cellulose Insulation

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Received 01 September 2006; accepted 12 October 2006

Loose fill cellulose thermal insulation known as ecofiber, is a recycled product made from recovered newsprint and other paper feedstocks. The product consists of small tufts of paper, dry mixed with powdered chemical additives which improve the fire properties of the product and prevent mould growth. Loose fill cellulose insulation is used in new and renovating buildings. To warrant appropriate thermal-technical conditions and lifetime of this material it needs to take notice to the moist state of enclosures. When moisture content is known in building enclosures, loss factor of thermal conductivity due to materials dampen and select applicable thickness of thermal insulating material can be exactly estimated.

The research results of moisture content of loose fill cellulose insulation in exploitation buildings are presented. Moisture content of cellulosic insulation is determined in one- and two floor buildings with masonry walls made of two layers of briks and with different thickness of insulating material layer. Also the influence of moisture content on the thermal conductivity is determined.

Keywords: loss-fill cellulose insulation, moisture content, thermal conductivity.

1. INTRODUCTION

Majority buildings are insulated with inorganic fibrous materials – mineral wool – which accounts for 60 % of European market, and organic foamy materials – expanded and extruded polystyrene and to a lesser extent polyurethane – which accounts for some 27 % of the market [1]. In recent years there is a growing interest in other thermal insulating materials, especially more ecological and with better overall energy performance (relationship of production energy and energy saving effect during use). One of such materials is loose fill cellulose thermal insulation. Cellulose insulation is used in U.S. since the 1940s, in Korea and Northland – more than 20 year, in Denmark this type of insulation is used for only a relatively few years [2 – 4]. Loose fill cellulose insulation is manufacturing In Lithuania since 1993s using technology and equipments of Finish concern. Loose fill cellulose is produced from pure cellulose waste, derived from paper production or from shredded newsprint (about 80 % by weight) and chemical additives – borates (9 % – 12 %) and boric acid (8 % – 10 %) [5]. These chemical additives are used for fire and mould prevention. The proportion of these materials in different countries often varies [2, 6, 7]. The investigations of borates and boric acid showed that there is no negative effect on the human health [8].

Loose fill cellulose insulation is also used due to other positive factors such as: low thermal conductivity, fire resistant, all the cavities are easily filled, building elements are without a vapour barrier of plastic, a lot of paper waste is removed from waste stream, good overall energy performance [2, 3, 9]. Cellulose insulation is used in new and renovating buildings. There are three methods of use cellulose insulation. Dry loose fill cellulose insulation is installed in attics and walls with pneumatic blowing machines. Existing walls may be insulating by blowing insulation through access holes. The holes may be at the top, bottom, and either inside or outside the building. A variety of methods are used to insulate new walls with dry cellulose. Techniques include using jigs or forms to fill open face cavities prior to insulation of sheetrock. Various types of permanent retainers are also using in walls, crawl spaces, or cathedral ceilings. Cellulose insulation spray-applied in wet form is a self-supporting material. It relies on water, adhesive, or a combination of both to build bond strength to a substrate and within itself. Spray-on products can be used in wall cavities (fully open and dried before covering) or on other suitable exposed walls or overhead surfaces [10].

Properties of loose fill cellulose insulation of different manufacturers often differ due to different raw material and technological factors. As it is shown in [2] these differences in most part influence on the thermal conductivity. Other test data [7, 9] approve this fact, where thermal conductivity of cellulose insulation varies from 0.035 to 0.045 W/m^2K. Measurements for insulations with known amount of chemical additives showed a negligible effect of the fire retardant on the thermal properties of the insulation [2]. The measurements of temperature, materials density and moisture content showed more significant influence on the thermal properties [2, 3, 6, 9]. The density of loose fill cellulose depends on the application. In attics, it is using as free blown with density from 24 kg/m^3, with the density in walls to 70 kg/m^3 [6, 7]. Furthermore, when performances of loose fill cellulose insulation is estimate it needs to take account into climatic influence [3].

The aim of this work is to determine moisture content, its distribution and changes in time in enclosures of exploitation buildings and to estimate influence of moisture content on the thermal conductivity.

2. EXPERIMENTAL

The specimens taken out from the buildings enclosures in October month (before moisture accumulation period)

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and in April month (after moisture accumulation period) for the determination of moisture content of loose fill cellulose insulation were used. The specimens were taken out not only from continuous walls, but also from sections under and over windows. Few specimens were taken out from every object. The specimens were distributed into 3 – 5 parts through the all thermal insulation layer and every parts were put into single cup on purpose to determine changes of moisture content through the all thickness of thermal insulating layer.

The specimens with thickness of 25 mm – 32 mm for the determination of thermal conductivity of moist cellulose insulation were used. Steady state thermal flow settles rather and mass changes are less in thin materials layer. Every measurement of thermal conductivity were started with maximum moisture content and continue measurements after periodical desiccation of specimen in oven at temperature 60 °C until moisture content reaches zero value. Final moisture content of specimen was calculated straightway after measurement of thermal conductivity. Moisten of specimen was done by method of water vapour diffusion and condensation in specimen. The specimen was hold over the water 3 – 6 days. The water temperature reached about 52 °C and was controlled by the thermostat. The specimen before thermal conductivity measurement was hold one day in a climate chamber with a temperature of 20 and relative humidity at ~97 %.

3. RESULTS AND ANALYSIS

Experimental investigation of moisture content of loose fill moisture content in exploitation buildings with one and two floors are presented. The walls of these buildings are made of two layers of bricks. Between these layers, loose fill cellulose insulation of 5, 6, 7, 9 or 12 cm thickness is used. The density of cellulose insulation varied from 50 kg/m^3 to 70 kg/m^3. The exterior walls surface was made of plaster and the exterior surface without finish.

204 determinations of moisture content of cellulose insulation are done. Statistical data are presented in the Table 1. In all cases, average values of materials moisture content, independent on the season of investigations and layer thickness varied from 8.9 % to 15.3 % by weight. Moisture content of material from exterior layer in all cases was about 13 % larger than from interior layer. Through the all observation period, average value of moisture content of material from exterior layer was 13.2 %, from middle layer – 12.9 % and 11.7 % – from interior layer. It demonstrates enough law of moisture distribution. It was also determined moisture content of material in continuous wall (12.8 %) in sections under windows (10.9 %) and in sections over windows (13.3 %). Therefore, statistical analysis were done using all determined particular values of moisture content, independent on early said factors, i.e. on specimen place in wall and layer. Through the observation time of 2 year, average values of moisture content in the observed walls changes marginally – from 11.5 % to 13.2 % by weight. It defines the permanence of materials moisture content in time. The experimental data indicate that moisture does not accumulate in the cellulose insulation layer, but removes to the outside. Exterior brick wall layer transmits moisture and leads to dry the material. That approves and practical data about use cellulose insulation in lightweight brick walls in Finland and Sweden, where air layer between exterior layer and cellulose insulation is eliminated [11]. Statistical data manipulation based on the bulk of experimental data shows that moisture content of loose fill cellulose insulation used in lightweight buildings enclosures can be estimated by average value of all period of investigations $\overline{W} = 12.4\,\%$ by weight with standard deviation $S_r = 2.3$ %. Moisture content of cellulose insulation by maximum value $W_{\max}$, with the probability $(1 - \alpha) = 0.9$, is:

$$W_{\max} = \overline{W} + k_s \cdot S_r = 12.4 + 1.28 \cdot 2.3 \approx 15.4\,\% , \quad (1)$$

where k_s is the factor, depending on the number of observation, $\Sigma n = 204$ [12].

Initial moisture content depends on materials composition, on the moisture relationship with capillary-porous material and on the technological parameters. Later moisture content depends on the type of exterior enclosure and exploitation conditions.

Estimation of moisture influence on the thermal conductivity of dispersive materials, as well as of cellulose insulation, is very complicated. There is undetermined moisture relationship with such material [13].

Quantitative influence of moisture content on materials thermal conductivity we have determined experimentally. In the experiment, the density of dry loose fill cellulose insulation was about 53 kg/m^3, and maximum moisture content about 60 % by weight. Influence of moisture content on thermal conductivity of cellulose insulation (see Fig. 1) we have estimated through value $\Delta\lambda_w$, %, which was determined by the formula:

$$\Delta\overline{\lambda}_w = 0.63 \cdot W_s^{1.23} \quad (2)$$

with standard deviation $S_r = 0.134$, where W_s is moisture content of cellulose insulation, by weight %.

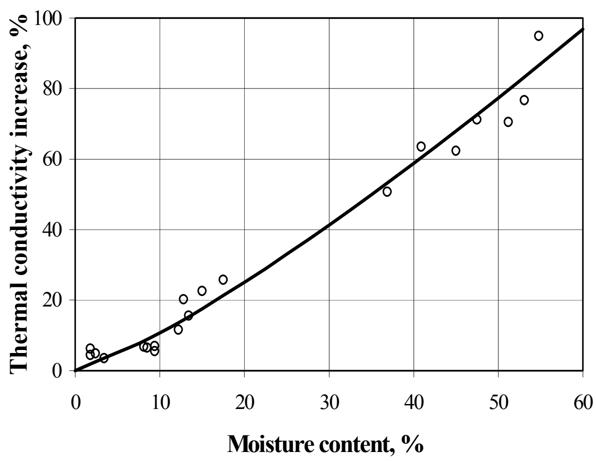

Fig. 1. The dependence of thermal conductivity increase on moisture content of cellulose insulation

The maximum values max $(\Delta\lambda_w)$ may be expressed by the following equation:

$$\max(\Delta\lambda_w) = \Delta\overline{\lambda}_w (1 + t_{\alpha,N-1}\, S_r) = 1.28\, \Delta\overline{\lambda}_w , \quad (3)$$

where $t_{\alpha,N-1}$ is the value of Students *t*-statistics,

Table 1. Average moisture content values of loose fill cellulose insulation investigated in exploitation buildings

Locality and number of investigated object	Exploitation time, year	Average thickness of insulation layer, cm	Observation period											
			1999 October month (before moisture accumulation period)			2000 April month (after moisture accumulation period)			2000 October month (before moisture accumulation period)			2001 April month (after moisture accumulation period)		
			$n^{*)}$	$\overline{W}$	S_r	n	$\overline{W}$	S_r	n	$\overline{W}$	S_r	n	$\overline{W}$	S_r
Kaunas														
1	4	6	5	10.1	0.58	5	8.9	1.19	6	8.9	0.50	6	10.6	1.08
2	2	7; 5**)	6	14.7	2.01	6	14.3	1.76	6	15.3	2.55	6	14.4	1.96
3	2.5	5	11	12.1	1.12	12	11.1	1.64	9	11.5	0.70	9	11.6	0.59
4	5	9; 6	12	13.8	2.96	12	12.9	2.01	6	12.4	3.96	9	13.9	2.10
	Total per year		34	12.8	2.49	35	11.9	2.39	27	12.0	3.06	30	12.6	2.12
Kėdainiai														
5	5.5	12.9	27	12.6	1.41	24	11.8	1.73	–	–	–	–	–	–
6	5.5	9	15	14.3	2.98	12	11.1	1.61						
	Total per year		42	13.2	2.23	36	11.5	1.69						

$n^{*)}$ is number of specimens, $\overline{W}$ is average moisture content values, % by weight, S_r is standard deviation;
**) building enclosures with different thickness of loose fill cellulose insulation.

depending on the confidence level and on the tests number ($N = 21$) [12].

Influence of moisture content on thermal conductivity of cellulose insulation with maximum moisture content 60 % by weight may be calculated by equations (2) and (3). Thermal conductivity of moist material with chosen moisture content value can be calculated using following equation:

$$\lambda_w = \lambda_0 \left(1 + \frac{\max(\overline{\lambda}_w)}{100} \right), \qquad (4)$$

where λ_w is thermal conductivity factor of moist material, W/m·K; λ_0 is thermal conductivity factor of dry material, determined experimentally.

On the basis of experimental investigation it is established that average value of thermal conductivity $\Delta\lambda_w$ increases about (1.2 – 1.5) %, and the maximum value $\max(\Delta\lambda_w)$ about (1.6 ÷ 2.0) % for 1 % of moisture content. Maximum values are used when moisture content of cellulose insulation reaches more than 30 % by weight.

4. CONCLUSIONS

1. It is estimated experimentally that moisture content of loose fill cellulose insulation used in lightweight enclosures average value of all period of investigations reaches $\overline{W}$ = 12.4 % and the maximum value $W_{\max}$ reaches 15.4 %.

2. Moisture content of material from exterior layer in all cases is about 13 % larger than from interior layer. It is also determined, there are no significantly differences between moisture content of material in continuous wall, under and over windows parts.

3. It is established that average increase of thermal conductivity $\Delta\lambda_w$ reaches about (1.2 – 1.5) %, and the maximum value $\max(\Delta\lambda_w)$ about (1.6 ÷ 2.0) % to 1 percent of moisture content.

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Presented at the National Conference "Materials Engineering'2006" (Kaunas, Lithuania, November 17, 2006)