LOW-EMISSION HEAT INSULATION FOR ROOF CONSTRUCTIONS

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Abstract
This research was carried out to start the discussion on the amount of harmful emissions that are emitted in producing building and insulation materials for roof constructions. Usually, for the improvement of energy efficiency of buildings and reduction of the embodied thermal energy, effective thermal insulation solutions for the external building envelope have to be provided. From the buildings available for the analysis, in Latvia there were selected multi-apartment buildings of separate series with a uniform composition of roof constructions. Within the context of renovation works, the reports of energy audit for the buildings contain recommendations referred to improvement of the thermal performance of roofs. Using mutually comparable energy efficiency report data, there was drawn up an averaged model of a five-storey multi-apartment residential house. There were taken into account legislative documents relating to thermal engineering of buildings: LBN 002-01 'Heat engineering of building boundary constructions' and LVS EN ISO 6946: 2007 'Building components and building elements – Thermal resistance and thermal transmittance', and moisture regime according to LVS EN ISO 13788: 2001 'Hygrothermal performance of building components and building elements – internal surface temperature to avoid critical surface humidity and intersatial condensation – calculation methods', which states that the roof constructions should be free from possibility of water vapor condensation. In this study, there were calculated energy savings obtained by improving thermal resistance of the roof constructions and the opposite primary energy consumption for the production of building materials. As a result, there is obtained environmentally friendly roof construction.
Key words: insulation materials, primary energy, energy efficiency, roof constructions.

Introduction

When increasing thickness of the existing thermal insulation layer in buildings under renovation or providing additional insulation of new buildings, there is projected the expected thermal energy savings expressed in megawatt hours. The saved megawatt hours are equivalently expressed in CO_2 emission savings, the amount of which depends on the type of the fuel.

To produce thermal energy for heating, usually in conjunction with CO_2 emissions, the atmosphere is polluted with acid creating NO_X, SO_2, OH^- chemical compounds, which are recognized as causes of acid rains. The primary air pollution, caused by the production of thermal energy, is expressed in CO_2 emissions as this is an indicative figure – the smaller amount of CO_2 emissions is discharged into the atmosphere, the smaller is presence of other harmful chemical elements in flue gasses of the boiler house (Woolley, 2005).

The total CO_2 emission savings per year, resulting from reduction of the embodied thermal energy and CO_2 emissions which in their turn result from production of materials for construction of buildings, must be positive. By improving the energy efficiency of buildings, there are projected cash savings on the account of thermal energy savings but in the list of measures improving energy efficiency of buildings, there is included thicker thermal insulation levels, for the production of which enormous amounts of energy are spent in plants.

Embodied energy or primary energy (GJ m^{-3}) is the term used to describe the total amount of energy used in the raw materials and manufacture of a given quantity of product. For products specially made for their insulating properties, it is true that all will probably save many times more energy during their life than is consumed in their production. Most will achieve energy break – even in months or years when compared to uninsulated structure. For a building to be green it is essential for the environmental impact of all its constituent parts and design decisions to be evaluated. This is a much more thorough exercise than simply adding a few green elements such as grass roof or a solar panel. The purpose of the digest is to help designers, specifiers and the clients to make relatively objective decisions about the environmental impact of materials, products and building solutions with some reasonably hard facts, at least as far as the current state of the art (or science) permits (Woolley, 2005).

The aim of research was to develop an alternative roof construction made from nature friendly materials and low primary energy use for production of insulation materials to reduce outflow CO_2 and other amount of acid compounds in atmosphere. For theoretical research, energy efficiency rating data was collected from eight energy audit reports made in heating season of year 2010 to 2011 (Table 1).

Table 1

The data of energy audits for five-storey buildings through additional insulation of the roof construction

Address	Series	Heated area, m^2	Initial rating of energy efficiency, kWh m^{-2} per year	Savings, kWh m^{-2} per year
Jelgava, Asteru 6	103	3,958.7	163.0	13.3
Jelgava, Pasta 55	103	1,358.1	150.4	13.8
Jelgava, Pulkveža O.Kalpaka 35A	103	4,120.3	170.9	12.8
Salacgrīva, Pērnavas 10	103	3,188.8	154.5	15.9
Jelgava, Lielā 32	316	2,233.0	134.6	14.1
Jelgava, Lielā 34	316	2,184.5	167.5	15.1
Jelgava, Raiņa 9	318	2,541.2	153.5	13.3
Jelgava, Uzvaras 2	318	2,318.4	137.1	13.3
Average:		**2,737.9**	**153.9**	**14.0**

Materials and Methods

In order to carry out research on the embodied energy for production of materials for roof structures and analyze moisture processes, there was adopted a concept consisting of six parts:

a) identification of the combined roof structure for the existing buildings;
b) energy audit data collection, which lists improvement measures for roof constructions in the same conditions;
c) recording of the required energy consumption for materials listed in the improvement activities;
d) comparison of the thermal energy savings with the amount of energy required for the production of building materials;
e) useable renewable resources;
f) analysis of moisture processes in the event of an existing and alternative structure.

For the analysis of the roof structures, there was chosen a standard covering for the top floor of buildings, which consist of light concrete and brick walls with hollow covering panels for floor and flat roof constructions (typical for 103^{rd}, 316^{th} and 318^{th} series of multi-apartment buildings in Latvia). We paid attention to these series of buildings as the development dynamics of energy efficiency improvement measures for multi-apartment buildings in Latvia is currently in an early stage. The structure of the combined roof constructions (Fig. 1) is the same in all of these serial buildings. For calculated in energy audits and included in this research five-storey buildings with combined roof constructions, the thermal transmittance values (U) were as follows: calculated before renovation U = 1.016 to 1.020 W m^{-2} K^{-1}, after renovation projected U = 0.201 to 0.207 W m^{-2} K^{-1} (LVS EN ISO 6946). Normative U value is 0.211 W m^{-2} K^{-1} (LBN 002-01). The heating areas of five-storey buildings range from 1,358.1 to 3,958.7 m^2, the original energy efficiency assessment is measured from 134.6 to 170.9 kWh m^{-2} per year.

The analysis of energy audit data was carried out for five-storey buildings (Table 1). In all the research pertinent energy audits there is recommended an additional thermal insulation of the roof construction with a 16-cm-thick thermal insulation layer, resulting in the projected savings within the limits from 12.8 to 15.9 kWh m^{-2} per year. For complementing the roof structure of the existing buildings (Fig. 1), rock wool panels in two layers, 12 cm and 4 cm in thickness, were recommended for the thermal insulation.

According to the data in Table 1, for a standard five-storey building with a combined roof construction, the heated area is 2,737.9 m^2, the measured energy efficiency rating before the improvement measures is 153.9 kWh m^{-2} per year, and the projected savings through the additional thermal insulation of the roof construction with solid rock wool insulation of 16 cm in thickness – 14.0 kWh m^{-2} per year. In this case, the roof area may be taken equal to the area of one floor, i.e., dividing the heated area by five, there was obtained the roof area of 548 m^2.

Table 2

The embodied energy for the production of heat insulating materials (Woolley, 2005)

Material	Embodied energy (GJ m^{-3})
Plastic insulation (EPS, XPS)	4.05
Foamed glass	2.70
Mineral wool	0.83
Cellulose fiber	0.48
Sheep's wool	0.11

For the purpose of taking measures for improving the building envelopes, thermal insulation materials are needed, in addition, each of them has a different amount of the embodied energy (Table 2; Woolley, 2005).

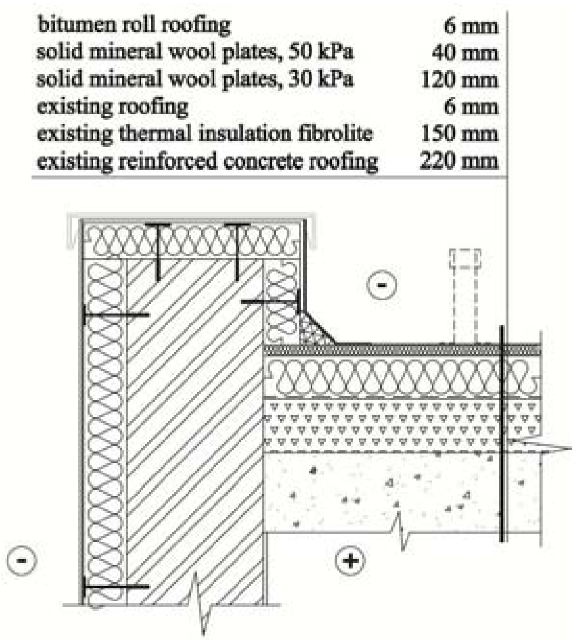

Figure 1. The structure of the roof construction for the existing building projected in the energy audit.

Results and Discussion

The thermal energy savings per year, when insulating the roof construction with the average area of 548 m^2, the average heated area amounts to 2,737.9 m^2 and the savings – 14.0 kWh m^{-2} per year for each square meter of the heated building, resulting in the calculated 38,330 kWh or 38.33 MWh per year.

For the production of one square meter of the mineral wool insulation 16 cm in thickness, according to the data of Table 2, the required energy amounts to 0.133 GJ m^{-2}. Together over the entire roof area calculated above, for the production of the thermal insulation materials, the embodied energy amounts to 72.88 GJ. Knowing that one joule is one watt per second, it is calculated that over the entire roof area, the embodied energy amounts to 20,250 kWh or 20.25 MWh. It is important to note that in the process of producing the mineral wool, in addition to the CO_2 pollution, there occurs emission of NO_X, SO_2, OH^- chemical compounds generating acid rains. The tiny mineral wool dust settles down in the human respiratory tract and irritates the skin (Woolley, 2005).

In the light of the results of calculations, when performing the thermal insulation works in the rock wool thermal insulation materials, the amount of energy embodied in the production of materials, in nature disperses in around 6.4 months. This means that when thermally insulating roof constructions, the total thermal energy savings per year are greater than the amount of the embodied energy in the production of building materials. It should be noted that the planned CO_2 emission reductions in the air through the roof thermal insulation of the existing buildings with mineral wool, in fact, will be on 53% lower.

If the rock wool insulation is replaced by cellulose fiber insulation in a wooden frame (Fig. 2), the required thickness of the insulation layer is 18 cm and for the production of such composite structures, the required energy amounts to 18,040 kWh or 18.04 MWh. For the production of timber, the adopted primary energy amounts to 0.26 GJ m^{-3} (Sustainable homes…, 2010).

Fig. 2 presents the (2nd version) roof construction with the calculated heat transfer coefficient U = 0.204 W m^{-2} K^{-1}, additionally calculating the ventilated layer of air and moisture resistant plywood U = 0196 W m^{-2} K^{-1}. The amount of the embodied energy for the production of the 2nd type of the roof construction materials, in nature disperses in around 5.7 months. The cellulose fibers and timber production do not contribute to emission of chemical compounds, which are considered to be the causes of acid rains.

For the roof structure solution with the cellulose fiber insulation, calculation was done following the standard LVS EN ISO 13788: 2001, according to which there is formed a non-essential vapor condensation possibility in the construction. This calculation did not take into account the air exchange of the ventilated layer and output effects of aeration, which convincingly provides a construction free of possibility to form a steam condensate. In turn, in the renovated roofs where for the improvement there is not dismantled the existing waterproofing layer, in parallel constructing a new waterproofing on the outside, a combined water vapor condensation and evaporation processes with a positive overall annual balance take place. This means that, so far, for standard renovated roofs under the influence of insufficient ventilation of the internal layers there can arise serious problems with the accumulated steam condensate (Krēsliņš and Borodiņecs, 2007).

In the 1st and the 2nd version, the roof constructions are considered to be alike in terms of construction costs as the cellulose fiber insulation is cheaper than the rock wool plates, so the woodwork in the 2nd version of the construction does not raise the cost of the total solution.

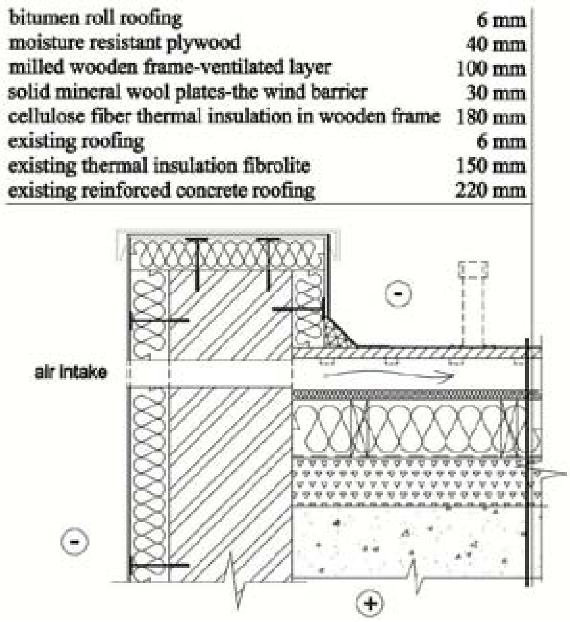

Figure 2. An alternative solution of the roof construction of the existing building with a cellulose fiber thermal insulation (concept based on Фокин, 1973).

Conclusions

In order to have a positive balance of CO_2 reduction, for each roof construction of thermally insulated multi-apartment building, it is allowed to produce on 1.8 times more insulation material of rock wool (2.1 times in the event of the cellulose fibers).

There was obtained coherence with the number of the thermally insulated buildings and the allowed number for the next year, which is approximately twice the amount, provided that CO_2 emissions will not be reduced but the balance of the chemical substances NO_X, SO_2, OH^- generating acid rains in the atmosphere will be increased.

Within the roof renovation measures of having the rock wool insulation, the actual CO_2 emission reduction amounts to 47% of the projected one, and respectively 53% if there is used the cellulose fiber insulation in a wooden frame.

The roof construction with a ventilated layer is safe from the possibility of water vapor condensation, but with horizontal roofs without air movement and adequate aeration solutions there is high probability for a lasting vapor condensation.

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