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Water vapour by diffusion and mineral wool thermal insulation materials

Диффузионное влагопоглощение теплоизоляционных изделий и минеральной ваты

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Ключевые слова: изоляция; диффузионное влагопоглощение; влажность; полиизоцианурат; минеральная вата; влажность; влагопоглощение; относительная влажность

Abstract. This article is aimed at determining the absorption of moisture by diffusion of mineral wool and polyisocyanurate over a long-term period. The task of increasing the thermal insulation properties of enclosing structures is most relevant for the erection of new buildings or structures, as well as for the repair of existing. The method models operating conditions in which thermal insulation product absorb moisture from both sides at high relative humidity of air (100%) and pressure difference of water vapour over a long-term period. The moisture absorption by diffusion of mineral wool and polyisocyanurate were obtained after 28 days of exposure to temperature and pressure drop of water vapor. Significant changes in moisture content of mineral wool were observed. From the results obtained, it can be concluded that polyisocyanurate has a lesser absorption property of water vapor, which is an important attribute in its operation.

Аннотация. Повышение теплоизоляционных свойств ограждающих конструкций является одной из основных задач строительства на сегодняшний день. Метод, приведенный в данной статье, моделирует условия эксплуатации, при которых теплоизоляционный материал поглощает влагу с обеих сторон при высокой относительной влажности воздуха (100%) и разности давлений водяного пара в течение длительного периода времени. Было произведено сравнение диффузионного влагопоглощения образцов полиизоцианурата (PIR) и минеральной ваты в течение 28 суток. Результаты показали, что диффузионное влагопоглощение у теплоизоляционного материала из полиизоцианурата (PIR) значительно ниже, чем у теплоизоляционного материала из минеральной ваты, что имеет большое значение в ходе его эксплуатации.

1. *Introduction*

The demand for environmentally friendly and healthy products is steadily increasing. This also applies to building materials, which can have great effect on human health. It is not surprising that new environmental friendly construction materials including thermal insulation are still actively studied. Demand for thermal insulation materials is increasing due to the growing costs of energy resources. Obtaining natural and environmentally friendly thermal insulation materials has become a topical issue nowadays, when thermal insulation materials are being extensively used (Muizniece, 2016). The most important challenge in the building sector worldwide is the reduction of the energy consumptions. In 2010, buildings accounted for 32% of total global final energy use (equal to 117 hexaJoules), 19% of energy-related GHG emissions, 51% of global electricity consumption, 33% of black carbon emissions, and an eighth to a third of F-gasses emission according to different accounting conventions in F-gasses data [1]. Control of indoor climate systems, ventilation, heating and air conditioning systems usually implies a high energy and

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economic costs. For heat exchange between the flows of supply and exhaust air are typically used air-to-air heat exchangers. Heat exchangers produce a transfer of tangible (visible) energy due to temperature difference on the surfaces. However, after a long period, the temperature difference between the air flows in the air intake is usually reduced and as a consequence some of the energy becomes insignificant. Another typical energy-saving solution is the introduction of ventilated facades using external or internal air, for reduction of thermal loads [2]. The GHG emissions from the building sector more than doubled between 1970 and 2010, reaching nowadays a value around 10 GtCo2 eq/y (Naldi, 2017). In harsh climatic conditions, the use of thermal insulation in buildings is necessary and is gradually becoming a mandatory requirement in many countries particularly as energy becomes more precious and demand increases (A.Abdou). In this regard, the problem related to the search of technology for energy-efficient construction has become a vital one. It is necessary to introduce not only energy-efficient designs, but also to apply meters and energy-saving technologies that allow to achieve and save on normative indicators of heat energy consumption, the corresponding class assigned to the building [3].

The task of increasing the heat-insulating properties of enclosing structures is most relevant for the erection of new buildings or structures, as well as for the renovation of existing facilities. Thermal protective properties of the fence depend on the design solutions used in this construction materials, the operating conditions of the building. There are many ways to insulate buildings, the most common are insulation with fibrous structure and polymer insulation. Along with the traditional and well-developed materials in the construction industry, new thermal insulation materials are appearing on the market, the physical and mechanical characteristics of which are not fully understood. PIR also belongs to this material. In the technical characteristics of this material, indicated by the manufacturer, there is no such indicator, important from the point of view of thermos-physical properties of the material, as sorption humidity. The manufacturer indicates only the value of the thermal conductivity of the material in the dry state. Meanwhile, it is known that, depending on the level of humidity under operating conditions and the sorption properties of the thermal insulation material, its actual (operational) value of thermal conductivity can differ significantly from the experimental values in the dry state.

The thermal conductivity of insulation materials is greatly affected by their operating temperature and moisture content, yet limited information is available on the performance of insulating materials when subjected to actual climatic conditions. Many parameters should be considered when selecting thermal insulation, including cost, compression strength, water vapor absorption and transmission and, most importantly, the k-value of the material when considering thermal performance of buildings and relevant energy conservation measures [2]. Together with heat transfer modes, phase changes of vapor moisture, although not strictly an energy transfer mechanism, should also be considered in heat transfer analysis since state changes absorb and release large quantities of heat [9]. This means that both vapour flow and moisture absorption are important, and they typically are more critical in insulating materials with open cell structures than with closed cell ones (Naldi, 2017).

The way thermal insulating materials resist to heat flow depends on microscopic cells in which air or other gasses are trapped. Thermal insulating materials resist heat flow as a result of the countless microscopic dead air-volumes. In fact, the thermal resistance of the air entrapped within insulating materials is mainly responsible for their low thermal conductivity. Meanwhile, creating small cells or a closed cell structure within the thermal insulation across which the temperature difference is not large, reduces the radiation heat transfer mode (Naldi, 2017).

Typically, air-based insulating materials do not exceed the thermal resistance of still air. However, some foam insulations such as the polyurethane encapsulate fluorocarbon gas instead of air within the insulation cells to obtain higher thermal resistance (R-value) than the air (Naldi, 2017).

PIR plate based on polyisocyanurate, as the thermal insulation material with the lowest the indicator of heat conductivity, has been extensively used in the USA and Western Europe for a long time, more than 10 years (Nastya). In North America, the roof insulation market shows that polyisocyanurate is the most widely used roof insulation, covering more than 50 % of all commercial new or re-roofing applications. This is probably due to the often nominal double of thermal resistance of the polyisocyanurate when compared to fiberglass or rock wool insulation. These last products have generally a larger market share for vertical building elements and in several European countries (Naldi, 2017).

Due to high performance indicators, the insulation is a considerable interest both for developers wishing to improve the energy efficiency of the constructed buildings, and for private clients interested in the most effective heat insulating material (Nastya). Many benefits justify the adoption of thicker layers of thermal insulation in buildings. In fact, the use of thermal insulation in buildings helps in reducing the reliance on mechanical air-conditioning systems to realize comfortable buildings, and it allows to save energy by reducing the heat flux through the building envelope. Meanwhile, the reduced energy demand achieved by using more effective thermal insulating layers also reduces the needed HVAC equipment. The thermal insulation in building enclosure extends the periods of indoor thermal comfort, especially between seasons, and by keeping buildings with smaller temperature fluctuations, it helps in preserving the integrity of building structures, increasing their lifetime (Naldi, 2017).

The basis for the preparation of polyisocyanurate is methylene diphenyl diisocyanate, which at a high temperature and in the presence of catalysts is able to react with itself, partially transforming into a tri-isocyanate-isocyanurate chemical compound. It is a rigid molecule of the ring structure, which is positively reflected on the physical properties of the final product.

This high-tech insulation polyisocyanurate (abbreviated – PIR) – a close a relative of a well-known polyurethane foam (PUR). Polyurethane possesses exceptional properties such as the high resistance to open fire (group combustibility G1) and low thermal conductivity (in the dry state) among the polymers is not more than 0.024 W/m^2. In addition, the PIR plate does not absorb moisture and is distinguished by a high resistance to compression.

At present, a number of articles have been written on the sorption humidity of insulating materials with a fibrous structure showing a change in this parameter over time during operation, which leads to its increase [4], or reflecting the efficiency of using multi-layered enclosing structures with mineral wool insulation in comparison with with an unheated wall, in which the sorption characteristics are greater [5]. For polymer insulation, foam polyisocyanurate, only the main characteristics characterizing the material have been studied and determined, such as: low flammability (G1), high heat-saving capacity, lightness and strength [6, 7].

Many of the works are related to the determination of the thickness of thermal insulation by calculating the temperature fields and aimed at improving the individual bearing elements of the enclosing structure [8].

The purpose of this work was to determine the thermo-physical properties of slabs from foam polyisocyanurate with soft liners (PIR) with a density of between 30 and 45 kg/m_3 and analogues. plates from mineral wool ROCKWOOL Facade Batts, density $\rho = 130$ kg/m_3

To achieve this goal, it was necessary to solve the following tasks:

1. Using experimental methods based on National Standards of Russia GOST and GOST EN methods, to determine physical and mechanical characteristics of two types of insulation.

2. Analyze the results and obtain the main evidence base for the correction of normative documents in the field of heat-insulation materials. At this stage, experimental studies were carried out to determine water absorption, diffusion moisture absorption for a long time, sorption humidity and thermal conductivity of the samples.

2. *Methods*

The test methods were selected in accordance with the work program presented by NAPPAN-Russian Association of Manufactures of Polyurethane Sandwich Panels.

The method simulates the operating conditions under which the samples absorb moisture from both sides at high relative humidity, approximately 100 % and the difference in water vapor pressure over a long period of time, from water to the form. The sample is subjected to a temperature and pressure drop of water vapor for 28 days while maintaining the water temperature (50 ± 1) °C and the temperature on the opposite side of the sample (1 ± 0.5) °C.

Materials:

- plates of mineral wool with a thickness of 50 mm;
- PIR plates 50 mm thick with double-sided lining aluminum foil 50 μm thick;
- PIR plates with a thickness of 50 mm without lining.

The experiments were carried out according to the requirements of the National Standard of Russia EN 12088-2011 Thermal insulating products in building applications. Method for determination of long-term moisture absorption by diffusion.

Sizes of samples were measured in accordance with EN 12085. A panel of mineral wool was cut using an insulation knife, in order to obtain the required lengths and widths equal to 500 and 500 mm, respectively. Samples were weighed to the nearest 0.1 g to determine the initial mass. The sample was then placed on the frame of the container. Since the sample was lined on both sides, experiments will be proceeded with a lined surface, with either side of the sample being placed on the frame facing upwards. The lower edge of the sample is sealed around the perimeter of the frame. The width of the sealant was equal to 10 mm. A thermally insulated cooling plate is placed on the upper surface of the sample.

The sample is exposed to temperature level and pressure drop of water vapor for 28 days, while maintaining the water temperature (50 ± 1) °C and the temperature on the opposite side of the sample (1 ± 0.5) °C. Every 7 days the sample is turned over. After 28 days, the sample is removed from the container and the water with its surface is removed with a paper or other suitable tissue. The sample is weighed and the final mass is determined.

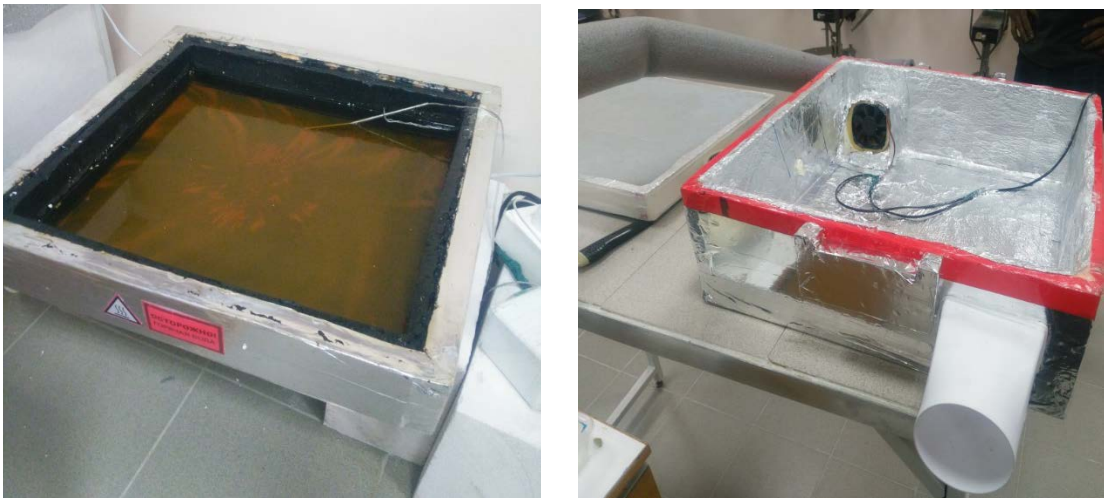

Figure 1. Heating plate with water and Cooling plate

A panel of mineral wool was cut using an insulation knife, in order to obtain the required lengths and widths equal to 500 and 500 mm, respectively. The size and shape of the specimens were determined according to the standard EN 12085. Linear dimensions of the PIR panels were received in prefabricated sizes of 500 and 500 mm. The apparatus for providing hot air, i.e. the hot disk, does not require particular restrictions regarding the shape but must be capable of heating the container with water at a constant temperature of (50 ± 1) °C: for this reason, a thermostat was connected to regulate the temperature inside the container.

The samples were conditioned for at least 6 hours at a temperature of (23 ± 5) °C before the test in a climatic chamber. In case of disagreement, the samples were kept at a temperature of (23 ± 2) °C and relative air humidity (50 ± 5) % for the time specified in the standard, and in its absence – in the technical conditions for the product of a particular type, but not less than 6 h. The samples were then weighed to an accuracy of 0.1 g to determine the initial mass (m0). A thermally insulated cooling plate is then placed above the upper surface of the sample to subject the sample to a lower temperature as a simulation of the winter period. Figure 1 shows a picture of the cooling plate with the sample thermally insulated to prevent air from escaping and support a balanced temperature and humidity conditions. On the other hand, the opposite side of the sample is placed in a thermally insulated container holding with water. Temperature in the container is controlled by a thermostat regulator at 50 °C. The sample is subjected to a temperature and differential pressure of water vapor for 28 days while maintaining the water temperature (50 ± 1) °C and the temperature on the opposite side of the sample (1 ± 0.5) °C. The sample is turned in the opposite direction every 7 days. After 28 days, the sample is removed from the container and water is removed from its surface with a paper or other suitable tissue. The sample is weighed and the mass after 28 days (mD) is obtained. For each sample, the amount of absorbed moisture is estimated by mass W_{dp} in kg/m_2 or by volume W_{dv} in percentage.

Figure 2 shows a flowchart scheme of the experiment to obtain the long-term moisture absorption by diffusion.

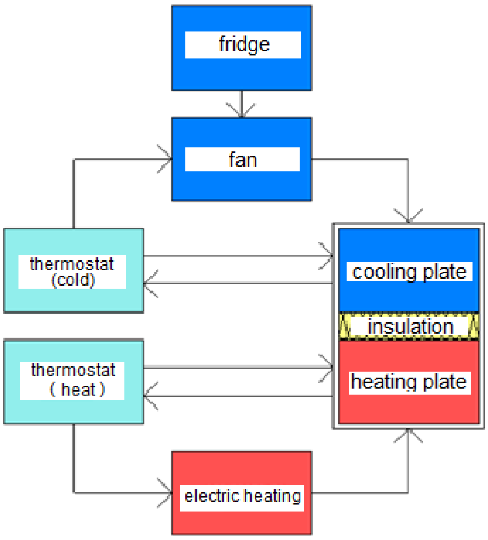

Figure 2. Flowchart scheme of the experiment

The thickness of the samples is equal to 50 mm for mineral wool and PIR (Table 1). Figure 5 shows a picture of the investigated samples.

In a second stage, the same samples were conditioned by setting temperature at (23 ± 5) °C and relative humidity at (50 ± 5) % under environmental conditions for the time necessary to reach the weight stabilization, in order to obtain moist samples.

Figure 3. Cooling plate with mineral wool

Water content (WC) was measured using the gravimetric method by means of Equation (1):

$$WC = (Ws - Wd)/Wd \cdot 100\% \tag{1}$$

where Ws and Wd are the weights of the examined and of the dried samples, respectively. A precision scale with a graduation of 0.01 g was used to measure weights.

Measurements of water vapour diffusion were performed on samples after different number of days for one of the PIR panels. In particular, four stages of measurements were performed: after 7 days, after 14 days, after 21 days and after 28 days.

In view of the fact that the samples were received with a delay, to date only one PIR sample has been exposed to temperature and a pressure drop of water vapor for 28 days. Table 2 shows the amount of moisture absorbed after 28 days.

Figure 4. Installation for testing in accordance with GOST EN 12088-2011

Sizes of samples were measured in accordance with EN 12085. Samples were weighed to the nearest 0.1 g to determine the initial mass. The sample was then placed on the frame of the container. Since the sample was lined on both sides, experiments will be proceeded with a lined surface, with either side of the sample being placed on the frame facing upwards. The lower edge of the sample is sealed around the perimeter of the frame. The width of the sealant was equal to 10 mm. A thermally insulated cooling plate is placed on the upper surface of the sample.

The sample is exposed to temperature level and pressure drop of water vapor for 28 days, while maintaining the water temperature (50 ± 1) °C and the temperature on the opposite side of the sample (1 ± 0.5) °C. Every 7 days the sample is turned over. After 28 days, the sample is removed from the container and the water with its surface is removed with a paper or other suitable tissue. The sample is weighed and the final mass is determined.

3. Results and Discussion

In view of the fact that the samples were received with a delay, to date only one PIR sample has been exposed to temperature and a pressure drop of water vapour for 28 days. Table 1 shows the amount of moisture absorbed after 28 days.

Table 1. Moisture absorption after 28 days

Sample	A, m^2	D, m	m_0, kg	m_d, kg	W_{dv}, %
PIR 1.1	0.25	0.05	0.53	0.563	0.3
PIR 1.2	0.25	0.05	0.52	0.566	0.4
MW 1	0.25	0.05	1.66	3.864	17.6
MW 2	0.25	0.05	1.69	3.622	15.5

A similar result is expected after 28 days. It is also predicted that mineral wool panels will absorb more moisture than both PIR panels.

Previously, no one has tested the diffusion moisture absorption of samples from polyisocyanurate. The obtained results confirm the presence of the dependence of the vapour content of thermal insulation materials of PIR and mineral wool on the relative thermal properties of the material. PIR with polymer structure of closed pores absorbs less moisture. MW with fibrous structure absorbs more moisture. Absolute values of the moisture absorption of the MW significantly exceed the analogous values for mineral wool by about 50 times

4. Conclusion

The obtained results testify to the differences in physical and thermal properties of the materials. It is shown that the PIR is more reliable than mineral wool by this indicator. However, due to the difference in structure of this material compared with mineral wool, it is not possible to make a final conclusion about which of the materials considered is more efficient in heat-insulating structures without additional studies. For a final conclusion, it is necessary to conduct a study to determine the thermal conductivity of the PIR in the wet state and compare these values with the analogous values for mineral wool or other competing materials. This will be used in the further of this material especially during operating conditions. The increase in the thermal insulation characteristics of the materials of the enclosing structures also makes it possible to avoid the costs of upgrading the sources of thermal energy.

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